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PROCEEDINGS

OF THE

American Institute

OF

Electrical Engineers

Volume XXIX
Number 7

July, 1910

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CONTENTS

Section I. Notes and Comments

Section II. Papers, Discussions, and Reports

(White Mountains Convention, June 28--July 1, 1910)

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Annual Convention White Mountains, June 28-July 1, 1910

The twenty-seventh Annual Convention of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS will be held at The Waumbek, Jefferson (White Mountains) N. H., June 28, 29, 30, and July 1, 1910.

Institute Headquarters.

The Institute headquarters during the convention will be at the Waumbek. On arriving each member should register at Institute headquarters and obtain identification badge. The convention sessions will be held in the hotel.

PROGRAM

(Subject to change)

TUESDAY, JUNE 28

AFTERNOON SESSION—2 O'CLOCK.

1. *President's Address.* Lewis B. Stillwell.
2. *Standardization Rules*, presented by the Standards Committee.

Electric Lighting Committee

3. *Headlight Tests*, by C. Francis Harding and A. N. Topping.
4. *Carbon Filament Lamps as Photometric Standards*, by Edward B. Rosa and G. W. Middlekauff.
5. *The Modern Oil Switch with Special Reference to Systems of Modern Voltage and Large Ampere Capacity*, by A. R. Cheyney.

WEDNESDAY, JUNE 29

MORNING SESSION—10 O'CLOCK

High Tension Transmission Committee

6. *Disruptive Strength with Transient Voltages*, by Joseph L. R. Hayden and Charles P. Steinmetz.
7. *The Electric Strength of Air*, by John B. Whitehead.
8. *Dielectric Strength of Oil*, by H. W. Tobey.
9. *Vector Power in Alternating-Current Circuits*, by A. E. Kennelly.
10. *Determination of Transformer Regulation Under Load Conditions and some Resulting Investigations*, by Adolph Shane.

*11. *Observation of Harmonics in Current and in Voltage Wave Shapes of Transformers*, by John J. Frank.

*12. *Parallel Operation of Three-Phase Generators with their Neutrals Interconnected*, by George I. Rhodes.

Telegraphy and Telephony Committee

13. *American Telegraph Engineering; Notes in History and Practice*, by William Maver and Donald McNicol.
14. *Telephone Engineering Around the Golden Gate*, by Arthur Bessey Smith.

Industrial Power Committee

15. *Interaction of Flywheels and Motors When Driving Roll Trains, by Induction Motors*, by F. G. Gasche.

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16. *Recent Progress in Exact Alternating-Current Measurements*, by Clayton H. Sharp and W. W. Crawford.

*These papers were presented at San Francisco May 5-7, 1910, but an opportunity for further discussion will be afforded at this session.

THURSDAY, JUNE 30

No Session; Trip to Mount Washington.

Thursday evening at 6 p.m. there will be a dinner and discussion by the Sections Committee and Section delegates.

FRIDAY, JULY 1

MORNING SESSION—10 O'CLOCK

Railway Committee

17. *Electric Locomotive Design*, by N. W. Storer and G. M. Eaton.
18. *A Method of Determining the Adequacy of an Electric Railway System*, by R. W. Harris.
19. *Power Economy in Electric Railway Operation—Coasting Clock Tests on the Manhattan Elevated Railway*, by H. St. Clair Putnam.
20. *Economy in Car Operation*, by Cyril J. Hopkins.

Friday evening there will be a dinner followed by a discussion by the Educational Committee.

ENTERTAINMENT

The Convention Committee announces the following events:

Tuesday evening, June 28, there will be a reception and dance at the Waumbek.

Wednesday afternoon, June 29, there will be golf and tennis tournaments. It is hoped that a considerable number will enter these contests. Those who desire to do so should notify the Institute registration clerk upon arrival.

Wednesday evening, June 29, a bridge tournament will be arranged for the ladies.

Thursday, June 30, is reserved to make the trip to Mount Washington, which will require practically the whole day. The trip will be made by rail, starting from the hotel about 7:25 a.m. and returning about 5:00 p.m. Excursion tickets will be about $5.00 per person.

Thursday evening there will be a "putting" contest for the ladies, by electric light.

Friday afternoon, July 1, there will be a ball game, and the golf and tennis tournaments will be concluded.

The committee has arranged for suitable prizes for the various golf and tennis tournaments.

There is an excellent 18-hole golf course on the hotel grounds, a baseball ground on the course, and a putting green near the hotel. Three tennis courts are also available. Automobiles and saddle horses may be hired at the hotel. Many points of interest are readily accessible from the hotel by rail or automobile.

TRANSPORTATION ARRANGEMENTS

Special summer excursion and circular tour rates to points in the White Mountains will be available for members and guests attending the convention. These rates will be in force the latter part of June on practically all transportation lines. Tickets should be purchased to Jefferson, New Hampshire.

Members should, therefore, consult their local ticket agents regarding routes and rates, preferably several days before they intend to start for the convention.

HOTEL RATES

Each member should arrange for his own hotel accommodations. Early application is desirable. Correspondence on this subject should be addressed to Charles V. Murphy, manager, "The Waumbek," Jefferson, New Hampshire. The hotel management has made the following rates, on the American plan, for members and guests who attend the convention. Single rooms $4 per day per person, with bath, $5 to 6; double rooms, for two persons, $7.50 per day, with bath $9; two single rooms, bath connecting, for two persons, $10 to $11 per day; one double and one single room communicating with bath, for three people, $13 to $15 per day.

Special Institute Meeting at New York

MAY 27, 1910

A special meeting of the American Institute of Electrical Engineers, under the auspices of the Railway Committee, was held in the auditorium of the Engineers' Building, 33 West 39th Street, New York City, on Friday evening, May 27, 1910. In the absence of President Stillwell, Mr. William McClellan, chairman of the Railway Committee, presided, and called the meeting to order at 8:30 p. m. Mr. McClellan then introduced Mr. W. H. Kempton, of the Ohio Brass Company, who read a paper on "The Application of Porcelain to Strain Insulators." At the conclusion of Mr. Kempton's paper Mr. McClellan announced that Mr. W. N. Smith, of Westinghouse, Church, Kerr and Company, would present a paper on "Electric Railway Catenary Construction", and that both papers would be discussed together. Mr. Smith then read his paper, which he illustrated with lantern slides. An interesting discussion followed the reading of the papers which was prolonged to a late hour. Those taking part in the discussion were: Messrs. Percy H. Thomas, C. J. Hixon, R. D. Coombs, and Charles Hart.

Conservation Meeting at Boston

JUNE 1, 1910

A meeting of the Boston Section in coöperation with the American Society of Mechanical Engineers and the Boston Society of Civil Engineers was held at Huntington Hall, Boston, on the evening of June 1, 1910. President Lewis B. Stillwell, of the A. I. E. E., was the guest and principal speaker. Previously to the meeting an informal dinner was given in honor of President Stillwell at the Hotel Tuileries, Boston, at which a large number of men prominent in engineering circles were present. At the close of the dinner, Mr. N. J. Neall, chairman of the committee on arrangements, called the party to order and spoke of the coöperative efforts of engineers in Boston and vicinity towards the erection of an engineering building and clubhouse. The subject was discussed by a number of those present.

At the Huntington Hall meeting President elect Jackson announced the election of the following officers of the Boston Section of the A. I. E. E. for the ensuing year: Chairman, J. F. Vaughn; vice-chairman, William L. Hooper; secretary and treasurer, Harry M. Hope. President Stillwell was then introduced, and read his paper on "Conservation of our Natural Resources. Mr. Stillwell reviewed the work accomplished since the conference of Governors at Washington two years ago. He showed how the work of committees and commissions has proceeded toward a definitely constructive policy, after which he went at length into the subject of conservation in its various phases. The paper was discussed by Professors D. C. Jackson, George F. Swain, Dr. A. E. Kennelly, and Messrs. C. T. Main and Henry F. Bryant.

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* Distribution

BY D. F. SCHICK

Of the various systems of electrical distribution, each may be classed under one of two headings; namely, direct and alternating current. These two systems may be still further subdivided into parallel and series systems of distribution. The direct-current parallel system, commonly known as the Edison three-wire system, is one of the oldest systems for the practical distribution of electrical energy. The general principal of this system involves the connection of two generators in series, having a tap carried out from the connection between them, thus providing three wires for the trans-

* Abstract of a paper presented before the Philadelphia Section of the American Institute of Electrical Engineers on March 14, 1910.

mission of the current. The capacity of the system may be increased by simply adding an even number of dynamos of similar voltage as the first pair, and connecting them in the same manner as described, or by the addition of batteries or single generators that generate current at double the voltage of the single generator operating in series. This system is used principally for furnishing light and power in the congested or built-up sections of a city.

The direct-current series system is used almost exclusively for street lighting. In this system all of the generating apparatus is manufactured in small units. Taking for illustration the Brush arc system as used for illuminating the streets of Philadelphia—the largest unit in general use in this system is 60 kw., having a capacity of 125 – 50-volt lamps at 9.6 amperes, giving a potential of 6250 volts across the machine terminals. Circuits are designed to supply current to a group of 125 lamps. Each group, containing its complement of lamps, is arranged to cover as small a district as possible. The object of this plan is to enable one quickly to locate troubles and re-establish the circuit in case of accident. Faults occurring on the series system are of three general classes—open circuits, grounds, and crosses. Of the three, open circuits are the most serious.

Alternating Current, Parallel Distribution.--In this system of distribution two sides have to be considered—the primary and secondary. Primary distribution involves five principal distributing systems, as follows: Single-phase, two-phase three-wire, two-phase four-wire, three-phase three-wire, and three-phase four-wire. Of these five systems the single-phase system has practically been abandoned for new work, as it is not well adapted for a power-load except for small motors. The two-phase three-wire and four wire, and the three-phase three- and four-wire are the systems mostly in general use. Secondary distribution is the most interesting branch of the alternating-current system for the distributing engineer, for on this side of the transformer the greatest possibilities of economy exist; economy in the amount of copper required to give satisfactory illumination, grouping transformers to reduce core loss, and in grouping services to provide a good load-factor for each transformer, for the power-factor of a transformer varies from 50 to 70 per cent at no load, whereas at 25 per cent full load it is approximately 98.5 per cent.

Lectures on Illuminating Engineering at Johns Hopkins University

The Johns Hopkins University, Baltimore, Md., offers for the academic year 1910-1911 a course of 36 lectures on the science and art of illuminating engineering. The course will have three objects: (1), to indicate the proper coördination of those arts and sciences which constitute illuminating engineering; (2), to furnish a condensed outline of study suitable for elaboration into an undergraduate course for introduction into the curricula of undergraduate technical schools; and, (3), to give practical engineers an opportunity to obtain a conception of the science of illuminating engineering as a whole. The lectures will be given under the joint auspicies of the Johns Hopkins University and the Illuminating Engineering Society. The subjects and scope of the lectures have been proposed by the Society, and approved by the University. The lecturers have been invited by the University upon the advice of the Society. The University will provide facilities for demonstrations at lectures, and will also have installed a working exhibit of apparatus for experimental work in light, illumination, and illuminating engineering. This apparatus will be at the disposal of those who attend, and an opportunity will be afforded to undertake laboratory work during the term of the lecture course under the supervision of trained experts of the University and the So-

ciety. A fee of $25.00 will be charged for admission to the course and the accompanying laboratory instruction. The complete course of 36 lectures will be given between October 26 and November 8, 1910, inclusive.

Conduction of Electricity through Gases*

BY DR. H. C. RENTSCHLER

Cathode rays consists of streams of negatively charged particles moving in a straight line, but capable of being acted upon and deflected by both magnetic and electric fields, and when so deflected for collection they give on collection a negative charge to an electrometer. If a stream of these negatively charged particles, each bearing a charge e and having a mass m be acted upon by a magnetic field H and an electric field E at right angles to each other, we may get with the magnetic field alone a force

Where V is the velocity of the particle

$$F = e\,v\,H$$

Where r is the radius of curvature of the path which can be measured by the deviation of the stream of particles from a straight line

$$F = \frac{m\,v^2}{r}.$$

Equating and solving

$$\frac{e}{m} = \frac{v}{r\,H}$$

If the electric field E be now put on and the value made such that it exactly counterbalances the deflecting force due to the magnetic field H we have

$$F^1 = E\,e = F = e\,v\,H$$

Solving $$v = \frac{E}{H}$$

Substituting in the second member of the equation for e/m we get

$$\frac{e}{m} = \frac{E}{H^2 r}$$

The results found for the ratios e/m were about 1/770 of the value for the hydrogen atom in electrolytes, and the value found for the velocity about 1/10 of the velocity of light. The values for e and m were found separately by making use of Stokes' law of falling particles in a viscous fluid. The sudden partial expansion of dust-free air saturated with water vapor causes condensation or ions as nuclei and the radius of the drops can be calculated from the rate of fall by means of Stokes' law. The total amount of water condensed may be determined by calculation from the amount of expansion and the total quantity of electricity by sweeping the drops into a plate connected to an electrometer. The number of drops can be calculated from the radius and the total condensed water, and the charge on each found by dividing the total charge by this number. The charge e so found was the same as that of the hydrogen atom. Moreover, the value of e/m and e and m were found to be the same for any gas or electrode material. If the cathode is made of a perforated sheet, then back of the cathode and in line with the holes we find the canal rays, which seem to consist of positively charged particles having a mass and a charge the same as the hydrogen atom. An interesting result found for the B-rays of radium, which seem to be similar to the cathode rays except that they have a much higher velocity, is that the value of m/e is much larger than the value found at low velocities. For instance, when the velocity is 2.85×10^{10} cm. per sec., the value of m/e is 3.09 times its value as found from cathode ray experiments. From this the conclusion is drawn that at least a large part of the mass is electromagnetic in character. If we now think of the electric field of force surrounding the electron moving with the particle, we can conceive

*Abstract of a lecture before the University of Missouri Branch on May 9, 1910.

that the electrostatic lines possess the property of inertia, and when the particle is suddenly stopped, as when the cathode rays or negative electrons strike the anticathode or the glass of the containing vessel, a pulse or vibration is sent along the electrostatic line and this pulse is the X-ray. If these pulses were periodically repeated we would have the vibration corresponding to light waves.

Applications for Election

Applications have been received by the Secretary from the following candidates for election to the Institute as Associates; these applications will be considered by the Board of Directors at a future meeting. Any member or Associate objecting to the election of any of these candidates should so inform the Secretary before July 20, 1910.

9567 Luck, F. J. W. Rio de Janeiro, Brazil
9568 Hatfield, K. G. S., Manchester, Eng.
9569 Motter, W. N., Milwaukee, Wis.
9570 Pierce, F. L., Milwaukee, Wis.
9571 Manzer, F. E., San Francisco, Cal.
9572 Allan, S. F., Oklahoma City, Okla.
9573 Barry, E. J., Potlatch, Idaho.
9574 Barley, A. T., Detroit, Mich.
9575 Chatterton, R. R., Ames, Iowa
9576 Picksen, G. W., St. Louis, Mo.
9577 Sano, S., Tokio, Japan.
9578 Hughes, E., Columbia, S. A.
9579 Klippelt, J. R., Uniontown, Pa.
9580 Prado, H. C., Columbia, S. A.
9581 Bodine, H. K., Stratford, N. J.
9582 Cousins, R. W., Gary, Indiana.
9583 Creagh, H., Manchester, Eng.
9584 Lauhren, N. L., Stockholm, Sweden
9585 Ojeda, A. M., Columbus, Ohio.
9586 Woodruff, L. S., West Allis, Wis.
9587 Barwise, A. H. O., Meerut, India
9588 Clizbe, R. E., Pullman, Ill.
9589 Leigh, A., San Jose, Cal.
9590 Starkey, W. C., Mansfield, Ohio.
9591 Mukerji, B. R., Allahabad, India.
9592 Hart, P. E., Montreal, Canada.
9593 Newnham, E., Springfield, Ohio.
9594 Voorhees, W. N., Brooklyn, N. Y.
9595 Kelsall, G. A., East Lansing, Mich.
9596 Moran, H. P., Denver, Colo.
9597 Partridge, G. W., London, Eng.
9598 Staeffen, H. G. E., Bridgeville, Pa.
9599 Howard, O. A., Chelsea, Mass.
9600 Irving, C., Los Angeles, Cal.
9601 Eckhart, N. A., Potter Valley, Cal.
9602 Radford, J. W. B., Madras, India.
9603 Taylor, A. Le R., Salt Lake City.

Total 37.

Section Meetings

Baltimore

The Baltimore Section held its regular monthly meeting on May 13, 1910. Mr. A. S. Loizeaux presented a paper entitled "Protection of Service in Large Electric Systems." The paper described the various precautions taken to safeguard continuity in a large public service electric system. After the meeting an informal supper and smoker was held, at which the discussion of the paper was continued.

Cleveland

The March meeting of the Cleveland Section was held on March 21, 1910. The program consisted of four papers, as follows: "Financial Aspects of Hydroelectric Development," by E. P. Roberts; "Cost of Hydroelectric Development", by R. C. Beardsley; "Gas Engine Costs and Efficiencies", by Mr. Merriman; "Turbine Economics", by Mr. Dreyfus. Fifty-seven members and visitors were present.

On April 25 a committee was appointed to nominate officers for the ensuing year. Dr. P. W. Cobb then addressed the members on "Physiology of Illumination." At the conclusion of the address there was a supplemental talk by Dr. McLeod and Dr. Hyde. The total attendance numbered 65 members and guests.

The final meeting of the Section for the year was in the form of a banquet given on the evening of May 16 at Webb's Restaurant. The guest of honor was Mr. Charles F. Scott, of

Pittsburg, who gave an address on the development of the electrical industry during the last 20 years. The report of the nominating committee was then read and accepted, and the following officers were elected: Chairman, A. M. Allen; secretary, Howard Dingle; treasurer, F. M. Hibben; managers, J. C. Lincoln, L. P. Crecelius, W. M. Skiff.

Fort Wayne

The Fort Wayne Section held its regular meeting on May 19, 1910. The meeting was preceded by a dinner at the Anthony Hotel. A number of business matters were first discussed, after which Mr. A. A. Serva, of the Fort Wayne Electric Works, presented a paper on "Photometry."

Milwaukee

The third meeting of the Milwaukee Section was held in the Plankington House, Milwaukee, on May 17, 1910, with Chairman W. H. Powell presiding. Mr. Calvin W. Rice, secretary of the American Society of Mechanical Engineers, gave a short talk on the formation of the Section and its affiliation with the local engineering society. He assured the members of the A. S. M. E. present of the desire of that national body to foster local interest in engineering meetings and discussions by similar support to any group of members desiring to hold meetings. The subject of the evening was a discussion on "Electrical Mine Hoisting", which was opened by Mr. W. L. Bliss. Mr. L. E. Bogen followed with an abstract of the paper by Messrs. Rushmore and Pauly, printed in the April 1910 PROCEEDINGS. Mr. W. A. Neill then read a paper on different types of steam hoisting gear. Mr. T. E. Barnum took up various electrical systems from the standpoint of ease and safety of control, emphasizing the fact that no matter how efficient a system might be theoretically, the practical efficiency was really based on ease and rapidity of operation, and reliability. The cost of control apparatus, liability to derangement, adaptability to automatic control and travel limiting devices, and methods of emergency operation, were all considered. Mr. H. W. Cheney took up the subject of water rheostat control versus metallic rheostats, particularly for large alternating-current motors, and described some schemes used in European practice. He then gave a detailed description of such a control now in service at the mines of the Woodward Iron Company in Alabama, which is probably the only one of large size in the United States. The results obtained are said to be very gratifying to the designers, the control being smooth, fast as desired, and at the same time slow enough to prevent accidental short circuiting of all resistance. Mr. Charles E. Lord spoke of the development of some of the popular systems from a historical standpoint as shown by a most thorough search of patents relating to the subject. The meeting was held jointly by the Milwaukee Section and the Engineers' Society of Milwaukee. There was a total attendance of about 90 members of both societies.

Minnesota

The Minnesota Section held a meeting in the Builders' Exchange rooms, Minneapolis, Minn., on Tuesday evening, May 3, 1910. Professor Kavanaugh, of the University of Minnesota, abstracted the Institute paper by E. D. Latta, Jr. on "The Gas Engine in Railway and Lighting Systems." He also led the discussion, which was participated in by Mr. C. W. Tubby and others. Photographs of the installation were exhibited by Mr. Tubby.

Pittsburg

A "kink" meeting was held by the Pittsburg Section in the lecture room of Carnegie Hall on the night of May 10, 1910. The meeting was given over to short talks on new methods or short cuts by a number of engineers representing various industries connected

with the electrical profession. Mr. H. A. Pharo, of the Pittsburg Railways Company, gave some interesting notes on repairs made on a burned commutator on a generator which was out of circuit only 15 minutes. A large hole which had been burned in the commutator was filled with plaster of paris, dried out, and the generator cut in service again. Mr. Pharo also stated that the Pittsburg Railways Company maintained a portable unipolar generator driven by a Westinghouse type "G" direct-current motor, mounted on an express truck, the set being taken to various points in the district to calibrate meters and to make tests. The generators delivered 10,000 amperes at a low voltage. He also mentioned that commutators are turned up while the machines are being operated as motors by their own power. Ordinary cases of rough commutators are smoothed up by use of a sandstone prepared for the purpose. A method of determining the degree of good contact existing in brush type circuit-breakers is to place a sheet of good grade tissue paper on the contact and then close the breaker. When the breaker has again been opened the tissue paper will show what portion of the contact was poor.

Mr. K. C Randall, of the Westinghouse Electric and Manufacturing Company, showed by means of several designs how various groupings and connections of service transformers of different capacities and ratios could be worked out to give many useful combinations to deliver powers at required potentials in cases of emergency and still load the transformers properly.

Mr. Ralph W. Atkinson, of the Standard Underground Cable Company, gave some valuable information regarding the properties of insulating gums and compounds, and results from testing the viscosity with a viscosimeter. By means of the tests and the determination of the brittleness it is possible to classify compounds for various purposes, since experience shows that those compounds which are brittle become soft rapidly with rapid changes of temperature. By these classifications one can determine what insulating compound to select for use in impregnating, bearing in mind that the brittle compound will crack when subjected to sudden shocks. Mr. Atkinson uses this method for testing viscosity as described by Mr. Sanborn in the *Electric Journal* for March 1910.

Mr. Henry W. Fisher, of the Standard Underground Cable Company, described a new method of measuring the viscosity of compounds, by means of a simple steel cylinder bored with holes to hold the compound and the thermometer. This cylinder is so designed and operated that there is very little uncertainty about the temperature at which the compound melts. The uncertainty in this regard, as measured by the apparatus used by Sanborn, is his chief objection to that method.

Mr. F. E. Wynne, of the Westinghouse Electric and Manufacturing Company, gave some short methods for quick calculation of the conductors necessary for street railway service, both alternating current and direct current.

Mr. F. K. Singer, of the Central District and Printing Telegraph Company, showed a typical trouble diagram of a telephone system with a view of exemplifying how any trouble in electrical circuits could be reduced to a system by a trouble diagram and then systematically studied out until by making certain tests and comparing the results with the diagram the defective element could easily be located with the least difficulty and delay.

In the discussion which followed the papers Mr. Henry W. Fisher described by request the new insulating material called "bakelite", made by Mr. Baekland and described at a meeting of the American Electrochemical Society held in Pittsburg on May 7. Samples were shown and an explanation given of the method of manufacture from phenol and formaldehyde.

PITTSFIELD

The May meeting of the Pittsfield Section was held in the Wendell Hotel on May 20, 1910, with 48 members present. Mr. E. E. F. Creighton, of Schenectady, N. Y., was the speaker and guest at the meeting, and presented a paper entitled "The Aluminum Cell Lightning Arrester."

PORTLAND, OREGON

The Portland Section held its annual meeting on May 17, 1910. Reports showed an average attendance of 42 members per meeting for the year. The following officers were elected: Chairman, L. B. Cramer; secretary-treasurer, F. D. Weber; executive committee, Paul Lebenbaum, E. E. Searing, and B. S. Durkee. Mr. H. R. Wakeman was selected to represent the Section at the annual convention. Mr. J. W. Newell, of the Pacific Telephone and Telegraph Company, then presented a paper on "The Handling of Telephone Traffic." After the paper had been read and discussed the entertainment committee served lunch, and several of the older members told of their experiences in early electrical work.

ST. LOUIS

The members of the St. Louis Section held their May meeting at Lippe's Restaurant, St. Louis, on the evening of May 11, 1910. After dinner the meeting was called to order by Chairman Langsdorf, for the transaction of business and election of officers for the ensuing year. Mr. G. W. Lamke was elected alternate to attend the annual convention of the Institute in the event of Chairman Langsdorf's inability to attend. A committee was appointed to coöperate with a committee of the Engineers' Club of St. Louis to arrange for joint meetings with that club. The following officers were elected: Chairman, G. W. Lamke: secretary, F. W. L. Peebles; executive committee, the chairman, the secretary and Messrs. A. S. Langsdorf, Oddgier Stephenson, and R. S. Pattison.

SAN FRANCISCO

The San Francisco Section held its usual monthly meeting on April 29, 1910, in the Home Telephone Company Building. Messrs. Allen G. Jones and William Shepard read a paper on "The Watt-Hour Meter", which proved of much interest to a large number of the members present. The paper was discussed by Messrs. Hull, Altmayer, Hillebrand and others.

TOLEDO

The June meeting of the Toledo Section was held at the Boody House, Toledo, on Friday evening, June 3, 1910. Mr. J. H. Boyden, patent expert, of Washington, D. C., addressed the members, taking as his subject "Automatic Block Signaling as Applied to Electric Roads." The address was illustrated by a large number of lantern slides. Mr. Boyden first described the early work in electric block signaling, which he explained by means of wiring diagrams. He then traced the development of the automatic signaling system as adopted to roads using electricity as motive power. To obviate interference with the signaling apparatus by power current, a change from direct-current-actuated signals, as at first used, to alternating-current-actuated signals on direct-current electric roads was made, introducing problems of rail return for power current, and inductive resistance between blocks to choke back signaling current while permitting the power return. Still further refinements are introduced where alternating-current power is used, when the signaling may be handled by a current of different frequency or by two-phase currents. These systems are designed to give caution and danger signals, the latter being given whenever a rail is broken or the apparatus is out of order, also when the next block is occupied by a train, thus insuring a maximum of safety.

The next regular meeting of the Section will be held in September.

Toronto

The Toronto Section held its last meeting for the year on April 29, 1910, at the Engineers' Club, Toronto. There was a total attendance of 74 members. Mr. E. E. F. Creighton, of Schenectady, N. Y., was the guest of the Section at this meeting, and presented an interesting paper on "Lightning Phenomena." Mr. Creighton discussed the subject very thoroughly giving practical demonstrations of the various phenomena described. He dwelt at some length on the new type of electrolytic lightning arrester, pointing out its advantages over the older types of arresters. An intelligent discussion followed the reading of the paper. Among those taking part in the discussion were Messrs. R. G. Black, A. L. Mudge, J. S. Richmond, E. L. Merrill, K. L. Aitken, and J. G. Jackson.

Washington, D. C.

Through the courtesy of Director S. W. Stratton, of the Bureau of Standards, the annual business meeting of the Washington Section was held in the physical building of that Bureau on May 18, 1910, the total attendance numbering 37 members and guests. Mr. Philander Betts was unanimously re-elected chairman of the Section, and Mr. H. B. Stabler, serving as secretary for an unexpired term, was elected secretary. The election of the remaining members of the executive committee resulted in the choice of P. G. Burton (re-elected), B. P. Lamberton, Jr. (re-elected), Earl Wheeler, and M. W. Buchanan. Following the business meeting Mr. Hayner Gordon, of Washington, gave a talk on "Wireless Telephony", with particular reference to the theory of high frequency oscillations and their generation and application to the wireless transmission of signals and speech. The meeting then adjourned to the engineering building, where an elaborately equipped wireless telephone station had been installed for the purpose of carrying on experimental work between that point and the laboratory of the U. S. Signal Corps at 1710 Pennsylvania Avenue. Mr. E. R. Cram, of the Signal Corps, assisted by Mr. Bermann, discussed and exhibited the singing arc and various other apparatus and accessories and with Mr. E. F. W. Alexanderson gave an exhibition of the 100,000 cycle alternator of the latter's design, the original machine, described by Mr. Alexanderson in the PROCEEDINGS of June 1909, it having recently been installed at the Bureau for use in the experiments now being conducted. An interesting discussion accompanied the exhibit, participated in by General James Allen, chief signal officer, U. S.A. General H. C. Dunwoody, Retired, General George H. Harries and others.

Branch Meetings

Bucknell University

The Bucknell University Branch, recently authorized by the Institute Board of Directors, held its first meeting on June 6, 1910. A constitution and by-laws were adopted, and officers were elected as follows: President, C. N. Brubaker; vice-president, R. C. Decker; secretary and treasurer, A. J. Huston; executive committee, W. K. Rhodes, chairman, J. C. Bank, G. H. Fagley, H. S. Bastian, S. W. Sweet. Sixteen members were present at the meeting.

University of Colorado

This Branch held its regular meeting on April 20, 1910. Mr. Woldridge, manager of the Boulder Electric Light and Power Company, gave a talk on his experience as a manager, in which he gave many valuable points on changing old systems so as to cut down losses and increase efficiency.

The Branch held a joint meeting with the civil and mechanical engineering societies on Wednesday evening, May 11, 1910. Fifty members of the three societies were present. Mr. Betts,

of the United States forestry service, read a paper in which he explained the object of the different testing stations located in various parts of the United States. The main object of the stations is for testing different kinds of woods with different preservatives so as to determine if it is not possible to replace some of the most widely used woods by other inferior woods which have been treated, and thus cut down the consumption rate. This rate in the United States is about 350 ft. per capita, which is about 10 times as great as in France. Mr. Betts mentioned particularly those woods used for telephone poles and railroad ties.

A business meeting was held on May 25, and the following officers were elected: President, Ernest Prince; secretary, R. B. Finley; treasurer, Frank Gilligan.

Colorado State Agricultural College

The last regular meeting of this Branch for the year was held in the electrical engineering building on May 18, 1910. Officers for the ensuing year were elected as follows: President, Alfred Johnson; vice-president, R. E. Drake; secretary and treasurer, D. E. Byerley; A. A. Catlin, collegian correspondent. The program consisted of a paper by Mr. E. J. Falloon on "A Central Heating and Lighting Plant." Mr. R. E. Drake gave a description of the Pennsylvania Railroad terminals in New York City. The Branch will resume its work in September.

University of Missouri

At the meeting of this Branch held on May 9, 1910, Dr. H. C. Rentscheler delivered a lecture on "Conduction of Electricity." An abstract of this lecture is printed elsewhere in this issue.

New Hampshire College

The annual meeting of the New Hampshire College Branch was held on June 3, 1910. The election of officers for the ensuing year resulted as follows: Chairman, Professor C. E. Hewitt; secretary, L. W. Bennett; executive committee, the chairman and secretary, and Mr. R. E. Carpenter.

Oregon Agricultural College

The Oregon Agricultural College Branch held its last meeting for the year on May 18, 1910. Mr. L. V. Hicks read a paper on "Edison's New Storage Battery", and Mr. C. A. French presented the sixth paper of the series on electrochemistry, under the heading of "Electrochemical Measurements." In a brief closing address Chairman E. R. Shepard commented upon the various features of the year's work, calling particular attention to the success of the plan setting aside a part of each program for the study of electrochemistry. He also commented upon the steady increase in the attendance at meetings during the year. The election of officers was deferred until the first meeting of the next season.

Pennsylvania State College

A number of special meetings were held by this Branch in May The following officers were elected for the ensuing three months: Chairman, W. D. Canan; vice-chairman, S. G. Gearhart; treasurer, G. W. Bower; assistant treasurer, W. R. Wiley; secretary, G. F. Speer; marshal, L. W. Parsons. On May 16 the members were addressed by Mr. Frederick Darlington, of the Westinghouse Electric and Manufacturing Company, on "The Electrification of Steam Railroads." On May 17 Mr. Darlington gave a lecture on "A Comparison of the Direct Current, Single-Phase and Three-Phase Systems in Railway Work." His first lecture was well illustrated by lantern slides showing in detail the types of locomotives, track, and overhead construction employed in each system. The second lecture was a comprehensive one, dealing with the relative advantages

and disadvantages of the different systems, with respect to cost and operation. On May 19 Mr. C. E. Downton addressed the Branch on "Methods of Management." Mr. E. T. Penrose, general manager of the Central Pennsylvania Electric Company, gave a talk on "The Relation of the Engineer to Public Service Corporations." The average attendance at the meetings was about 55.

STANFORD UNIVERSITY

At the meeting of the Stanford University Branch held on May 10, 1910, the following officers were elected for the ensuing year: Chairman, T. W. Snell; secretary, J. H. Leeds; treasurer, E. J. McCann, librarian, E. C. Woodcock. An amendment to the by-laws of the Branch relating to the presentation of papers and discussions was adopted.

WASHINGTON UNIVERSITY

The Washington University Branch held its final meeting for the year on May 24, 1910. Officers for the year were elected as follows: Chairman, George W. Picksen; vice-chairman, Chester Hardy. The election of the secretary was deferred until the fall. The paper for the evening was presented by Mr. Ballman, of the Wagner Electric Company. Mr. Ballman gave some inside facts regarding the construction of electrical instruments and their calibration. Refreshments were served after the adjournment of the meeting.

WORCESTER POLYTECHNIC INSTITUTE

The last meeting of this Branch for the year 1909-1910 was held on Friday evening, May 13, 1910. The subjects discussed were abstracts from the senior theses. Mr. W. Robbins gave an account of his work on "Bond Testing", conducted in and around Worcester, describing the various types of testing apparatus used, and the merits and disadvantages of each. In connection with his work Mr. Robbins obtained from electric railway companies in his section data on their methods and cost of testing, and a tabulated summary of this was given. Mr. C. C. Pilsbury spoke on "A Power Transmission System for the Worcester Consolidated Street Railway." Mr. Pilsbury explained the situation of the company as regards to obtaining power, and then showed by means of a map the present location of stations and traced out the proposed changes in the new layout according to his thesis. The subject of Mr. M. F. Clement's thesis was the "Development of Hydroelectric Power from Barre Falls and Transmission to an Industrial Plant." Mr. Clement treated the subject from the original survey to the complete development of the plant. A short business session followed the meeting, and the following officers were elected to serve for the coming year: President, W. C. Greenough; vice-president, G. I. Gilchrest; secretary treasurer, H. E. Hartwell; executive committee, S. A. Nimms, F. W. Butler.

Engineer-Indian Service

The United States Civil Service Commission announces an examination on July 13-14, 1910, to secure eligibles from which to make certification to fill a vacancy in the position of engineer in the Indian Service, at White Earth School, Minnesota, at $800 per annum, and other similar vacancies as they may occur in the Indian Service. For the specific vacancy mentioned above, examination in Branch 1 is required; and the Department desires men who have had some experience in charge of an engineering plant.

Owing to the widely varying conditions in the schools and agencies of the Indian Service, general engineering examinations will be given under the following separate branches:

Branch 1—STEAM ENGINEERING; time allowed, 3 hours.

Subjects	Weights
1. Practical questions (covering installation, repairs and operation of boilers and steam engines, and pumps)	60

Subjects	Weights
2. Experience in handling steam engines and boilers and pumps	40
Total	100

Branch 2—ELECTRICAL ENGINEERING; time allowed, 3 hours.

Subjects	Weights
1. Practical questions (covering generators and motors, switchboard apparatus, wiring for lighting and power)	60
2. Experience in handling electrical apparatus	40
Total	100

Branch 3—HEATING; time allowed, 2½ hours.

Subjects	Weights
1. Practical questions (covering heating by hot water and exhaust or live steam)	60
2. Experience in handling heating plants	40
Total	100

Branch 4—REFRIGERATION; time allowed, 2½ hours.

Subjects	Weights
1. Practical questions (covering systems of refrigeration and operation of necessary apparatus)	60
2. Experience in handling refrigerating apparatus	40
Total	100

Branch 5—GAS AND GASOLENE ENGINES; time allowed, 2 hours.

Subjects	Weights
1. Practical questions (covering operation of gas and gasolene engines)	60
2. Experience in handling gas and gasolene engines	40
Total	100

Branch 6—HYDRAULICS; time allowed, 2 hours.

Subjects	Weights
1. Practical questions (covering operation of water turbines and water wheels)	60
2. Experience in handling turbines and water wheels	40
Total	100

An applicant may take one or more of these, at his discretion. The prospects of appointment will be increased by successfully passing more than one of the branches indicated. Applicants should indicate in their applications the particular branch or branches in which they desire to be examined, and should state as definitely as possible the experience they have had which would tend to qualify them in the branches selected. Salaries range from $480 to $1,000 per annum but the majority of appointments are made at salaries of $720, $840, and $900 per annum. The age limit is 20 years or over on the date of the examination. Two days will be required in case more than three branches are taken.

This examination is open to all citizens of the United States who comply with the requirements, and this announcement contains all information which is to be communicated to applicants regarding the scope of the examination, the vacancy or vacancies to be filled, and the qualifications required. Examinations will be made in the principal cities throughout the United States. Applicants should apply at once to the United States Civil Service Commission, Washington, D. C., for application and examination Form 1800. In applying for this examination the exact title as given at the head of this announcement should be used in the application, and the particular branch or branches in which examination is desired should be indicated at the head of the application. As examination papers are forwarded direct from the Commission to the places of examination, it is necessary that applications be received in ample time to arrange for the examination desired at the place indicated by the applicant. The Commission will therefore arrange to examine any applicant whose application

is received in time to permit the shipment of the necessary papers.

Issued May 31, 1910.

Personal

MR. EINER A. BROFOS, electrical and telephone engineer, has returned from an extensive trip abroad.

MR. JAMES J. C. HATELEY has accepted the position of electrical engineer in the testing department of Allis-Chalmers Company, Milwaukee, Wis.

MR. F. W. MCKENZIE has left the Washington Water Power Company at Spokane, Wash., to become manager of the Fisher Electric Company, of Massillon, Ohio.

MR. P. D. WAGONER has been elected president of the General Vehicle Company, Long Island City, N. Y., succeeding J. Howard Hanson, who has withdrawn from the company.

MR. P. CONRAU PETERSEN, of the Central District Printing and Telegraph Company, Pittsburg, has permanently changed his residence from Muskegon, Mich., to Aspinwall, Pa.

MR. ALBERT M. HOWE, formerly laboratory assistant at the Rhode Island State College, has taken a position with the Old Colony Street Railway Company at Brockton, Mass.

MR. J. H. OGLE, formerly with the Bell Telephone Company of Missouri, St. Louis, Mo., has accepted the position of engineer with the Bradrick Machine Works, Porterville, Cal.

MR. J. F. HOWARD, until recently located at Jersey Shore, Pa., as experimentalist and designer, is now with the testing department of the General Electric Company, Schenectady, N. Y.

MR. H. G. BUTTERFIELD is engaged in general engineering work in the Rogue River Valley, with headquarters at Ashland, Oregon. Mr. Butterfield was formerly located at Houston, Texas.

MR. C. R. UNDERHILL, formerly with the Westinghouse Electric and Manufacturing Company, Pittsburg, Pa., is now chief engineer of the American Electric Fuse Company, Muskegon, Mich.

MR. W. D. PEASLEE has resigned his position with the Northern Electric Railway Company of California to enter the testing department of the General Electric Company at Schenectady, N. Y.

MR. OSKAR FRIEDRICH, formerly with the Westinghouse Electric and Manufacturing Company, Pittsburg, accepted on May 1 a position with the General Electric Company at Schenectady, N. Y.

MR. HARRY P. YOUNG, formerly with the Electrical Equipment Company, Atlantic City, N. J., has joined the engineering staff of the Anderson Carriage Company at its factory in Detroit, Mich.

MR. HANS J. MEYER AND MR. FRANCIS A. VAUGHN have become associated as consulting engineers, under the firm name of Vaughn and Meyer, with headquarters at 909 Majestic Building, Milwaukee, Wis.

MR. H. S. SLADEN, who for the last year has been associated with the American Power and Light Company, was recently appointed manager of the Wichita property of the Kansas Gas and Electric Company.

MR. W. H. REYNOLDS, of the construction department of the General Electric Company, is stationed at the Preston, Ont., substation of the Hydroelectric Commission of Ontario, now under construction.

Mr. William B. Newhall, consulting engineer, of Minneapolis, Minn., has moved his office to Raymondville, Cameron County, Texas, where he will be manager for the Southern Fruit Lands Irrigation Company.

Mr. H. C. Cushing, Jr., publisher of *The Central Station* and *Standard Wiring*, recently moved from 220 Broadway to larger offices in the Pulitzer Building, overlooking City Hall Square, New York City.

Mr. Arthur B. Stitzer, who has been with the Philadelphia Rapid Transit Company for almost twelve years, has accepted a position as assistant engineer with Ford, Bacon and Davis, 115 Broadway, New York City.

Mr. A. H. Fisher, formerly with the Guanajuato Power and Electric Company, Zamora, Michoacan, Mexico, has removed to Irapauto, State of Guanajuato, where he is in charge of operation for the same company.

Mr. George R. Wood, president of the Wood-Randolph Company, consulting electrical engineers, announces the removal of the company's offices from 1207 Park Building to 2329-2330 Oliver Building, Pittsburg, Pa.

Mr. R. Philip Clark, of the Schenectady office of the General Electric Company, is at present located in Denver, Colo., where he is making a study of lightning, particularly in its relation to street car operation.

Mr. H. C. Estabrook has been transferred from the construction department of the General Electric Company at Schenectady, N. Y., to the Cincinnati office, where he will take up sales work in the railway department.

Mr. R. C. Norman, formerly chief operator for the La Crosse Water Power Company at Hatfield, Wis., resigned on May 1 to enter the construction department of the Sanitary District of Chicago at Lockport, Ill.

Mr. E. H. Minehardt has resigned his position with the Housatonic Power Company at Gaylordsville, Conn. to enter the industrial control engineering department of the General Electric Company at Schenectady, N. Y.

Mr. J. J. Martindale, chief engineer and purchasing agent of the Northern Construction Company, formerly of Lansing, Mich., has located at Jackson, Mich., where the main offices of the company are now situated.

Mr. W. S. Doremus has assumed charge of a sales agency recently established by the General Electric Company at Erie, Pa. for its patrons in northwestern Pennsylvania. Mr. Doremus' address is 632 State Street, Erie, Pa.

Mr. Hubert Howson, of Howson and Howson, counsellors at law and solicitors of patents, announces the removal of their New York office to the Liberty Tower, 55 Liberty Street, corner of Nassau Street, New York City.

Mr. A. A. Tirrill, president of the Tirrill Manufacturing Company, announces the removal of the company's plant from Schenectady, N. Y., to Athens, Pa. The change was made on April 1, and the plant is now in operation.

Mr. G. A. Blucher, formerly with the San Antonio Gas and Electric Company, San Antonio, Texas, has resigned to become superintendent of the electrical department of the Union Light and Power Company of Fargo, N. D.

Mr. R. L. Noggle has resigned his position as foreman of electrical construction with the U. S. Reclamation Service at Minidoka, Idaho, to accept

a similar position with the Northern Idaho and Montana Power Company at Newport, Wash.

MR. W. F. HYNES, who has been with the Bullock Electric Manufacturing Company and the Allis-Chalmers Company for seven years, latterly in charge of the Spokane, Wash. office of the Allis-Chalmers Company, has resigned his position.

MR. JESSE H. ADKINS, who has been connected with the Allis-Chalmers Company for the past ten years, has been transferred from the construction department at Pittsburg to the sales organization at the Birmingham, Ala., office of the same company.

MR. HORATIO A. FOSTER, who is associated with Mr. B. J. Arnold of Chicago, and who has been located in Detroit for the past year appraising the property of the Detroit United Railways, is now in Pittsburg assisting in the study of the transportation problem in that city.

MR. F. H. FARMER has resigned his position as construction engineer with the Canadian Westinghouse Company to assume the management of the Montreal office of Messrs. Chapman and Walker, Ltd., Canadian agents for Dick, Kerr and Company, Ltd., and other European manufacturing companies.

MR. J. CHARLES RUNYON has been appointed designing engineer of the Post-Glover Electric Company, Cincinnati, Ohio, the largest electrical company in that city. Mr. Runyon has had extensive experience in the design of switchboards, automatic controllers, dynamos and motors.

MR. R. M. HOPKINS, for four years in the engineering department of the Alberger Condenser Company, has been transferred to the sales department of that company and the Alberger Pump Company. The general offices of these companies were moved on May 1 to 140 Cedar Street, New York City.

MR. WILLIAM F. DAWSON, who has been in Rugby, England, for the last five years, in charge of direct current design for the British Thomson-Houston Company, Ltd., has now returned to the General Electric Company, Schenectady, where he will collaborate with Mr. H. F. T. Erben on the same class of work.

MR. JAMES C. DOW has left the United Missouri River Power Company, after nearly eight years' service, and is now in the employ of the Great Falls Water Power and Townsite Company, in charge of the installation of the new 102,000-volt substation in Butte, Mont., which will receive power from Great Falls.

MR. NELSON S. HOPKINS, who for the last four years has been with the Wirt Manufacturing Company, of Burrage, Mass., manufacturers of electrical porcelain and specialties, recently resigned as treasurer and director to accept an appointment with the Sterling Engine Company, 1252-1274 Niagara Street, Buffalo, N. Y.

MR. HERBERT C. BROWN has been appointed superintendent of the Lewistown Coal, Gas and Light Company, Lewistown, Montana. Mr. Brown was formerly in the engineering departments of the Ontario Power Company and the Telluride Power Company, and for the last three years was associated with the Rocky Mountain Bell Telephone Company.

MR. J. A. SANDFORD, JR., who for the past year has been connected with the New York office of R. Thomas and Sons Company, has been transferred to the East Liverpool, Ohio, office of the same company. In his new position Mr. Sandford will have full charge of engineering work for the Lisbon, O.,

and East Liverpool, O., plants of the Thomas Company.

Mr. J. B. Fleming, for the last year engineer for the Mt. Whitney Power and Electrical Company, of Visalia, Cal., has gone to Goldfield, Nevada, to take charge of rebuilding that portion of the Goldfield Consolidated Mines Company's mill which was recently destroyed by fire. Mr. Fleming had charge of the original design and construction of the mill.

Mr. N. A. Carle desires to announce that he has opened an engineering office at 510 Central Building, Seattle, Washington. Mr. Carle will make examinations and reports on existing steam, electric and water power plants and mining properties, and will take over the supervision of such plants and operate them under the direction of the owner, or act in the capacity of consulting engineer.

Mr W. R. W. Griffin, formerly general superintendent of transportation of the New York State Railways, Rochester Lines, Rochester, N. Y., has accepted the position of general manager of the Ohio Valley Scenic Route, composed of the Steubenville and East Liverpool Railway and Light Company, the East Liverpool Traction and Light Company, and the Ohio River Passenger Railway Company, with headquarters at East Liverpool, Ohio.

Mr. C. G. Young, of the engineering firm of C. G. Young, which makes a specialty of compiling reports for financing, has taken additional office space, enlarging his present suite on on the eighth floor of 60 Wall Street, New York City, to meet the increasing demands of business. The concern is engaged largely in engineering and construction, devising plans, and methods of operation of public utilities and industrial companies.

Obituary

Joseph T. Wolfe died in Los Angeles, Cal., on May 6, 1910, after a brief illness. Mr. Wolfe was born on November 19, 1871, in Philadelphia, Pa. He entered the employ of the Westinghouse Electric and Manufacturing Company nearly 20 years ago, spending the first few years in the laboratory as a student, and later becoming foreman of the department in which the electrical experimental work was conducted. In 1898 he was appointed superintendent of the distribution circuits of the Colorado Electric Power Company at Cripple Creek, Colo. In 1900 he went to France where he had charge of the installation and operation of a substation in connection with the electrical features of the Paris Exposition. He then went to Melbourne, Australia, as general engineer and sales agent for Noyes Brothers. On his return to America several years ago he took up electrical work in connection with mining operations in Tonopah, Nevada. He was electrical engineer for the Tonopah Mining Company and superintendent of the Esmeralda Power Company. He was elected an Associate of the Institute on June 28, 1901. Mr. Wolfe was enthusiastically devoted to his work, in which he was very successful. He was a man of high character and fine personal qualities.

Raymond Dickerson died at his home in Middletown, N. Y., on June 9, 1910, at the age of 28 years. Mr. Dickerson was born in Orange County, N. Y., on January 9, 1882. After graduating from the Pratt Institute, of Brooklyn, N. Y., he worked for several years for a number of the large electrical companies, as engineer's assistant and draftsman. In the latter part of 1905 he entered the engineering department of the New York Edison Company, retaining his connection with this company to the time of his death. Mr. Dickerson was elected an Associate of the Institute on March 29, 1907. He is survived by his wife, and an infant son 11 months of age.

KENNETH McCASKILL, B. Sc., M. Sc. (McGill University), an Associate of the Institute, died at his home in Barb, Ontario, Canada, on April 10, 1910. Mr. McCaskill was born in Van Kleek Hill, Ontario, on March 9, 1876. After completing the course at the Schenectady works of the General Electric Company he entered the engineering department of the New York Central Lines as assistant electrical engineer, remaining with this company for two and a half years, during which time he was engaged on the electrification of the terminal in New York City. Early in 1909 he joined the staff of the electrical engineer of the Southern Pacific Company at San Francisco, where he had charge of the detail design and construction of the overhead work and electrification of the company's suburban lines. Although the fact was unsuspected by Mr. McCaskill, he was already at that time suffering from the malady which resulted in his death. Within three months after joining the staff of the Southern Pacific Company he was obliged to give up all active work and return to his home in Canada. Mr. McCaskill was a mason of an advanced degree, and stood high in fraternal circles. His brief professional career was long enough to show that in his early death the profession sustained a distinct loss. His patient, manly and courageous fight against the inevitable made a deep impression upon his associates. He was admitted to membership in the Institute as an Associate on Febrraury 26, 1910. His father, Alexander McCaskill, survives him.

Library Accessions

The following accessions have been made to the Library of the Institute since the last acknowledgment:

American Electrochemical Society. Hand-Book of the Pittsburg Meeting, May 4-7, 1910. n.p. 1910 (Gift of American Electrochemical Society.)

American Street Railway Investments. Annual volume 16th 1909. New York, 1909. (Gift of McGraw Publishing Co.)

Chicago. Public Works Department. Mayor's Message and Annual Report of Department of Public Works. 14th, 16th-18th, 20th, 22nd, 27th-29th, 31st-33d. Chicago, 1890, 1892-1894, 1896, 1898, 1902-1904, 1906-1908.(Gift of Chicago Bureau of Statistics.)

Iowa Engineering Society. Proceedings of Annual Meeting 22d. Iowa City, 1910. (Gift.)

Massachusetts Gas and Electric Light Commissioners. Annual Report 25th Boston, 1910. (Gift of Mass. Gas and Electric Light Commissioners.)

Montana State College of Agriculture and Mechanic Arts. Annual Catalogue 1909-1910. Bozeman, 1910. (Gift.)

Protection. A Brief Story of the Protection Afforded the Electric Motor and Motor-Driven Tools by the I-T-E Circuit Breaker. Philadelphia, 1910. (Gift of The Cutter Company.)

University of Tennessee. Register 1909-1910. Knoxville, 1910. (Gift.)

Verein beratender Ingenieure fur Elektrotechnik. Mitglieder-Verzeichnis und Satzunger. 1908. n.p. 1908. (Gift of C. O. Mailloux.)

Verein deutscher Ingenieure und Seine Arbeiten. 1910, Berlin, 1910. (Exchange).

La Vie et Les Oeuvres de E. Mascart. By P. Janet Paris, 1910. (Gift of Comité Electrotechnique Francais.)

Trade Catalogues

Central Electric Co., New York City. May 1910 price list of electrical supplies. 72 pp.

Emerson Electric Mfg. Co., St. Louis Mo. Bulletin No. 3138—Single phase induction motors. 3 pp.

——Bulletin No. 3217—Bipolar ventilated motors. 7 pp.

——Bulletin No. 3707—Electric buffing lathes for alternating and direct current. 3 pp.

——Bulletin No. 3962—Motors for family washing machines. 3 pp.

Engineering Electric Mfg. Co., Stamford, Conn. Bulletin No. 106—Direct current motors, dynamos, motor-generators, etc. 11 pp.

General Electric Co., Schenectady, N. Y. Bulletin No. 4723—Regulating pole rotary converters. 7 pp.

——Bulletin No. 4728—Thomson single phase high torque Watt hour meters. 11 pp.

——Bulletin No. 4729—Mazda economy light diffusers. 8 pp.

——Bulletin No. 4730—Gas-electric motor car, single truck type. 19 pp.

Pettingell-Andrews Co., Boston, Mass. Juice-June 1910.—A magazine, giving information about electrical supplies, manufactured by this Company. 16 pp.

Sprague Electric Co., New York City. Catalogue No. 321—Sprague electric fans. 35 pp.

——Catalogue No. 233—Sprague electric hoists. 24 pp.

——Catalogue No. 516—Sprague flexible steel armored hose for compressed air or steam. 28 pp.

Westinghouse Electric & Mfg. Co., Pittsburg, Pa.

——Supply sheets of their permanent electrical catalogue to replace old ones, superseded by more recent numbers. 28 sheets.

UNITED ENGINEERING SOCIETY

Annalen der Hydrographie und Maritimen Meteorologie. Year 38-date. Berlin, 1910. date. (Purchase).

Cyclopedia of Automobile Engineering. 4 vols. Chicago, 1910. (Purchase).

Journal für Gasbeleuchtung. General Register zum jahrgang 32-46 (1889-1903). München, 1905. (Purchase).

McNeill, Bedford Code 1908 edition. London, 1908. (Purchase). Tables for McNeill's Code 1908 edition.

Nevada State Controller. Annual Report 1905-1909. Carson City, 1906-1910. (Gift of Nevada State Controller.)

Ohio Railroad Commission. Report 4th Springfield, 1910. (Gift of Ohio Railroad Commission.)

Practical Instructions Relating to the Construction and use of the Steam Engine Indicator. Boston, Crosby Steam Gage & Valve Company, 1910 (Gift of Alfred B. Carhart.)

Society for the Promotion of Engineering Education. Proceedings. Volume 17. Ithaca, 1910. (Gift.)

GIFT OF AMERICAN GAS INSTITUTE.

American Gas Light Journal. vols. 56-67. New York, 1892-1897.

Association of Gas Engineers & Managers. United Kindgom. Reports of Proceedings 1887-1897. London, 1888-1898.

British Associations of Gas Managers. Report of Proceedings. 1876-1879. Title changed to Gas Institute in 1881.

Congres International de L'Industrie de Gaz. Compte rendu des Travaux Public par les Soins de la Société Technique de L'Industrie de Gaz en France. 15th-28th, 30th-36th Congress. Paris, 1888-1901, 1903-1909.

——Assemblée Générale Rapports Annexes. Paris, 1900.

Deutscher Verein von Gas und Wasserfachmännern. Verhandlungen 1903–1907. München, 1903–1907.

Gas Institute Transactions. 1884–1885. London, 1884–85. Early title to 1881, British Association of Gas Managers.

Incorporated Gas Institute. Transactions 1896, 1897, 1899, 1900. London, 1896–97, 1899–1900. Merged in 1902 to form Institution of Gas Engineers.

Incorporate Institution of Gas Engineers Transactions vols. 1–6, 8–12. London, 1892–1903. Merged with Gas Institute in 1902 to form Institution of Gas Engineers.

Institution of Gas Engineers. Transactions 1903–1908. London, 1903–08.

Progressive Age. vols. 9–14 (6 vols. in 3.) New York, 1891–1896.

OFFICERS AND BOARD OF DIRECTORS, 1909-1910.

PRESIDENT.

(Term expires July 31, 1910.)

LEWIS BUCKLEY STILLWELL.

JUNIOR PAST-PRESIDENTS.

HENRY GORDON STOTT. LOUIS A. FERGUSON

VICE-PRESIDENTS.

(Term expires July 31, 1910.)	(Term expires July 31, 1911.)
CUMMINGS C. CHESNEY.	JOHN J. CARTY.
BANCROFT GHERARDI.	PAUL M. LINCOLN.
CALVERT TOWNLEY.	PAUL SPENCER.

MANAGERS.

(Term expires July 31, 1910.)	(Term expires July 31, 1911.)	(Term expires July 31, 1912.)
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Bucknell University	May 17, '10	C. N. Brubaker.	A. J. Huston, Bucknell University, Lewisburg, Pa.
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Total, 31.

NOTE

The following paper is to be read at the 27th annual convention of the American Institute of Electrical Engineers at **Jefferson, N. H., June 28–July 1, 1910.** This paper is to be presented under the auspices of the High Tension Transmission Committee of the Institute. All those connected with the Institute and desiring to take part in the discussion of this paper may do so by being present at the meeting; or, if this is not possible, by sending in a written contribution.

Written contributions will be read at the meeting, time permitting, for which they are intended, either in full, in abstract, or as a part of a general statement giving a summary of the views of those taking the same position in the matter.

The principal object in getting out the paper in advance of the meeting is to enable and encourage those not in a position to attend the meetings to take part in the discussion by mail.

Contributions to the discussion of this paper should be mailed to **Ralph D. Mershon, Chairman, High Tension Transmission Committee, 60 Wall Street, New York,** so that they will be received not later than June 23, 1910.

(KENNELLY)

PROCEEDINGS

OF THE

American Institute

OF

Electrical Engineers.

Published monthly at 33 W 39th St., New York, under the supervision of

THE EDITING COMMITTEE

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Changes of advertising copy should reach this office by the 15th of the month, for the issue of the following month.

Vol. XXIX August, 1910 No. 8

The Jefferson (N. H.) Convention

The national character of the American Institute of Electrical Engineers was again emphasized by the twenty-seventh annual convention at Jefferson, N. H., the registered attendance from various parts of the continent being 178. This has been exceeded several times in the past, but the hotel was filled, the sessions well attended and the various entertainments were enlivened by enthusiastic participants. The weather was delightful, the accommodations excellent, and the mountain scenery at its best.

The various technical sessions were attended by those who were interested in the papers and discussions. The authors were very considerate in summarizing their papers, so that in most cases ample time was permitted for discussion, which was chiefly oral.

The session of Tuesday afternoon, July 28, was opened with President Stillwell's address on the "Conservation of Water Powers", which is printed in full beginning on page 1335 of Section II of this issue. On motion of Dr. C. P. Steinmetz, seconded by Mr. W. S. Lee, the Board of Directors was requested to bring the address to the attention of the proper government officials, as embodying the attitude of the Institute towards the questions involved.

The Standards Committee, represented by Chairman A. E. Kennelly, presented several amendments to the existing standardization rules, and a few entirely new rules, which are printed elsewhere in this issue. On motion of Professor George F. Sever, the convention voted that a circular be distributed to the membership with a view to eliciting suggestions and criticisms regarding the rules.

The following papers were then presented under the auspices of the Electric Lighting Committee, Professor W. Lispenard Robb, chairman; *Headlight Tests*, by Messrs. C. Francis Harding and A. N. Topping, of Purdue University: *Carbon Filament Lamps as Photometric Standards*, by Messrs. E. B. Rosa and G. W. Middlekauff, of the Bureau of Standards, Washington, D. C.; and *The Modern Oil Switch with Special Reference to Systems of Moderate Voltage and Large Ampere Capacity*, by Mr. A. R. Cheyney, of the Philadelphia Electric Company. These papers were discussed by Messrs. John B. Taylor, G. H. Stickney, H. Barker, C. P. Steinmetz, C. F. Scott, H. P. Wood, J. C. Lincoln, A. E. Kennelly, P. Junkersfeld, F. W. Harris, C. W. Stone, D. B. Rushmore, W. I. Donshea, and V. Karapetoff.

Wednesday morning's session was occupied with the presentation and discussion of five papers under the auspices of the High-Tension Transmission Committee, Mr. Ralph D. Mershon, chairman. The papers were: *Disruptive Strength with Transient Volt-*

ages, by Messrs. J. L. R. Hayden and Charles P. Steinmetz; *The Electric Strength of Air*, by Professor J. B. Whitehead; *The Dielectric Strength of Oil*, by H. W. Tobey; *Vector Power in Alternating-Current Circuits*, by Dr. A. E. Kennelly; and *Determination of Transformer Regulation Under Load Conditions and Some Resulting Investigations*, by Professor Adolph Shane. These papers were discussed by Messrs. D. B. Rushmore, V. Karapetoff, Percy H. Thomas, A. E. Kennelly, W. H. Pratt, E. E. F. Creighton, J. C. Lincoln, Charles F. Scott, Ralph D. Mershon, L. T. Robinson, John B. Taylor, W. W. Crawford, Gano Dunn, D. C. Jackson, and E. A. Wagner. Although no afternoon session had been scheduled, about fifty volunteers assembled at three o'clock and continued the discussion in spite of the counter diversions of golf and tennis, adjourning in time for the delayed opening of the baseball game.

Wednesday evening's session was devoted to the program of the Telegraphy and Telephony Committee, Mr. William Maver, Jr., chairman. This consisted of a paper on *American Telegraph Engineering*, by William Maver and Donald McNicol, which was discussed by Messrs. Ralph W. Pope, John B. Taylor, Gano Dunn, and William B. Hale; and *Telephone Engineering Around the Golden Gate*, by Mr. Arthur Bessey Smith.

Under the auspices of the Industrial Power Committee, Mr. David B. Rushmore, chairman, a paper was presented by Mr. F. G. Gasche, of the United States Steel Corporation, on *The Interaction of Flywheels and Motors When Driving Roll Trains by Induction Motors*. This paper was discussed by Messrs. Charles P. Steinmetz, Charles F. Scott, and Gano Dunn.

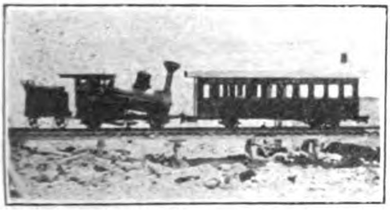
Thursday was entirely devoted to a railroad trip to the summit of Mount Washington. This was followed by a dinner in the "Bohemian Room" at The Waumbek, participated in by the Section delegates, past and present officers of the Institute, and representatives of the Branches. An open meeting followed in the "Music Room", Past-President Charles F. Scott in the chair, in the absence of Chairman Paul M. Lincoln, who had been called to Utah just prior to the convention. Brief oral reports of the work of the Sections during the year were made by the following delegates upon call of the chairman: M. C. Beebe, Madison, Wis.; J. M. Bryant, Urbana, Ill.; E. P. Burch, Minnesota; W. A. Hillebrand, San Francisco, Cal.; George A. Hoadley, Philadelphia, Pa.; A. S. Langsdorf, St. Louis, Mo.; A. A. Miller, Seattle, Wash.; E. L. Nichols, Ithaca, N. Y.;

Tiptop House, summit of Mount Washington, N. H., altitude 6201 feet. Summer temperature +30° to +50° fahr.; winter minimum -60° fahr.

W. H. Powell, Milwaukee, Wis.; H. B. Stabler, Washington, D. C.; H. W. Tobey, Pittsfield, Mass.; E. A. Wagner, Fort Wayne, Ind.; H. R. Wakeman, Portland, Ore.; H. L. Wallau, Cleveland, O.; J. B. Whitehead, Baltimore, Md.; H. P. Wood, Atlanta, Ga.; W. Edgar Reed, Pittsburg, Pa.; W. B. Hale, Mexico City, Mex.; Edward N. Lake, Chicago, Ill.; Charles P. Steinmetz, Schenectady, and J. H. Vaughan, Boston. The representatives of Branches present were: C. F. Harding, Purdue University, H. B. Dates, Case School of Applied Science, H. E. Hartwell, Worcester Polytechnic Institute, Adolph Shane, Iowa State College. The meeting was also ad-

dressed by President Stillwell and Past-President F. J. Sprague. President Stillwell introduced President-elect Dugald C. Jackson, who called attention to the stimulation in the activity and influence of the Sections during the past year, and invited the hearty coöperation of the members during his approaching term of office. Chairman Scott suggested a meeting of the Section delegates by themselves on Friday morning, Professor Hoadley, of the Philadelphia Section, being appointed chairman of the proposed meeting.

At the Friday morning meeting of the Section delegates, committees were appointed to suggest more effectual coöperation with the constituted authorities in the administration of Institute affairs.



Wood burning locomotive and single coach cog railway, Fabyan, N. H., to Tiptop House

The final session on Friday was primarily devoted to the presentation of four papers under the auspices of the Railway Committee, Mr. William McClellan, chairman, as follows: *Electric Locomotive Design*, by N. W Storer and G. M. Eaton; *A Method of Determining the Adequacy of an Electric Railway System*, by R. W. Harris; *Power Economy in Electric Railway Operation—Coasting Clock Tests on the Manhattan Elevated Railway*, by H. St. Clair Putnam, chairman Meetings and Papers Committee; *Economy in Car Operation*, by Cyril J. Hopkins. Among those who discussed these papers were: Messrs. William McClellan, A. F. Batchelder, F. J. Sprague, A. H. Armstrong, John B. Taylor, and G. H. Hill.

Recent Progress in Exact Alternating-Current Measurements was the title of the final paper read at the convention, by Clayton H. Sharp and W. W. Crawford. It was discussed by Messrs. V. Karapetoff, L. T. Robinson, W. H. Pratt, and C. P. Steinmetz.

Entertainment and Recreation

The goodly proportion of ladies present, supplemented by members who lean toward the social features of the annual convention, served to enliven the occasion, without interfering in the least with the technical part of the proceedings. The reception and dance on Tuesday evening served as a medium for forming new and renewing old acquaintances. The golf links and tennis courts were in active demand at all reasonable hours, while carriages and automobiles were available at the call of the ladies, who organized various driving parties to points of interest among the picturesque hills. None present, not even those who visited the summit of Mount Washington, fully appreciated the exemption from the intense heat which prevailed in lower altitudes and even on the seashore. The organized games and tournaments as arranged by the Convention Committee, and the card functions so admirably managed by Mrs. Stillwell, evoked well merited praise from all who participated.

Results of Contests

In the baseball game Wednesday afternoon the "Has-Beens" captained by Farley Osgood beat the "Never-Wasers" captained by W. S. Lee, by 13 to 11 in seven innings. Professor George F. Sever umpired, J. F. Vaughan was awarded the cup for the longest hit. Professor A. S. Langsdorf the cup for the greatest number of runs and W. S. Lee the cup for the greatest number of hits.

The tennis tournament (men's singles) brought out sixteen entries. The final match between Messrs. G. A. Sawin and C. T. Mosman was won by the former three sets to two. The

first prize cup was therefore presented to Mr. Sawin and the second prize to Mr. Mosman.

In the golf tournament the championship cup for the first eight was won by F. E. Donohoe for the second eight by N. W. Storer and for the third eight by M. P. Rice. In the qualifying round the cup for the lowest gross score was won by A. H. Armstrong. The cup for the handicap golf tournament was won by W. E. Reed.

The first prize in the ladies putting contest was won by Mrs. Walter I. Slichter the second prize by Mrs. Comfort A. Adams. In the "spook" golf putting contest Mrs. F. E. Donohoe and Mrs. A. H. Kruesi tied for first place and in the play-off Mrs. Donohue won the first prize and Mrs. Kruesi the second prize.

Directors' Meeting June 29, 1910

The regular monthly meeting of the Institute Board of Directors was held at The Waumbek, Jefferson, N. H., on Wednesday morning, June 29, 1910. The directors present were: President Lewis B. Stillwell, New York; Vice-President, Paul Spencer, Philadelphia, Pa.; Managers Percy H. Thomas, New York, David B. Rushmore, Schenectady N. Y., Charles W. Stone, Schenectady, N. Y., A. W. Berresford, Milwaukee, Wis., S. D. Sprong, New York, and secretary Ralph W. Pope, New York.

Eighty-two candidates for admission to membership in the Institute as Associates were elected.

Fifty-one Students were declared enrolled.

Six Associates were transferred to the grade of Member, as follows:

I. E. Hanssen, Electrical Engineer, Moss, Norway.

James Delmage Ross, Electrical Engineer, Seattle Municipal Light and Power Plant, Seattle, Wash.

John Harisberger, Superintendent and Electrical Engineer, Seattle-Tacoma Power Company, Seattle, Wash.

Walter Sherman Moody, Designing and Executive Engineer, Transformer Department, General Electric Company, Pittsfield, Mass.

Morton G. Lloyd, Associate Physicist, Bureau of Standards, Washington, D. C.

W. L. Abbott, Operating Engineer, Chicago, Edison Company, Chicago, Ill.

Associates Elected June 29, 1910

Adams, Kilburn Elie, Mechanical Engineer, Boston & Albany Railroad, Room 370 South Station, Boston, Mass.

Allen, Oliver Field, Salesman, Fort Wayne Electric Works, 30 Church Street, New York City.

Bale, Laurence D., Chief Electrician, Cleveland Railway Co.; res., 8710 Birchdale Avenue, Cleveland, Ohio.

Barney, Charles Asa, Electrician, National Tube Co.; res., 732 Chestnut St., Kewanee, Ill.

Berdon, Albert Eugene, Assistant Manager, Esterline Co.; res., 145 Andrew Place, West La Fayette, Ind.

Bicknell, George Wilder, Electrician, John Hancock Mutual Life Insurance Co., 49 Federal St., Boston, Mass.

Bobst, J. A., District Traffic Chief, Iowa Telephone Co., Des Moines; res., Sioux City, Iowa.

Bohan, William James, Mechanical Engineer, Northern Pacific Railway; res., 427 Dewey Ave., St. Paul, Minn.

Brown, Arthur A., Sales Engineer, Westinghouse Electric & Mfg. Co., 165 Broadway, New York City.

Brown, Fred Willets, Draughtsman, Pacific Gas and Electric Company; res., 237 9th Ave., San Francisco, Cal.

Bruninga, John Hermann, Patent Lawyer and Solicitor, McGill Building, Washington, D. C.

Clark, William, Electrical Engineer, General Electric Co., 84 State Street, Boston, Mass.

COFFIN, ARTHUR HOBART, Manager, Robbins & Myers Co., 176 Federal Street, Boston, Mass.

DANIEL, FRANK RUTTER, Fire Protective Engineer, Indiana Inspection Bureau, 1008 Lemoke Bldg., Indianapolis, Ind.

DART, HARRY EDSON, Electrical and Mechanical Engineer, Buck & Sheldon Inc., 60 Prospect Street, Hartford, Conn.

DAVIS, EDWIN GREELEY, Assistant Electrical Engineer, Interborough Rapid Transit Co., New York City.

DAVIS, HUGH GARNETT, Electrical Engineer, J. G. White & Co., Inc., 43 Exchange Pl.; res., 70 West 181st St., New York City.

DAVIS, JERALD FARMER, Illuminating Engineer, Mahoning & Shenango Railway & Light Co., Youngstown, Ohio.

FAGAN, WALTER M., Purchasing Agent, Pacific States Electric Co., 107 Security Building, Los Angeles, Cal.

FISHER, CHARLES MCCABE, Electrical Engineer, Spokane, Wash.

FLAGER, HAROLD JAMES, Engineer, Eastern Montana Electric Railway, Red Lodge, Montana.

FORSHUND, CHARLES FREDERICK, Power House Foreman, Sierra & San Francisco Power Co., Stanislaus Power House, Vallecito, Cal.

FOWLER, SAMUEL BARTLETT, Consulting Engineer, Barristers Hall, Pemberton Square, Boston, Mass.

GERHARDT, REGINALD BERNARD, Electrical Engineer, Spanish American Iron Co., Felton, Orient, Cuba.

GILBERT, HARRY NATHANIEL, Electrical Engineer, General Electric Co.; res., 747 Laurel Ave., Austin Sta., Chicago, Ill.

GILL, WILLIAM ADAMS, Electrical Engineer, Kamehameho Schools, Honolulu, T. H.

GLUCROFT, SAMUEL HYAM, Electrical Engineer, Glucroft & Glucroft, 44 Court Street, Brooklyn, N. Y.

GOODWIN, CASPER KELLER, Electrical Superintendent, West Side Lumber Co., Tuolumne, California.

HALBY, CHARLES FELIX, Superintendent, Transmission Lines, Mexican Light and Power Co., Mexico City, Mex.

HARRIS, FRANCIS WALLER, Superintendent and General Manager, Consolidated Light & Power Company, Ronceverte, W. Va.

HASELTINE, WILLIAM EDWARDS, Assistant General Manager, Holtzer-Cabot Electric Co., 621 Albany St., Boston, Mass.

HECKER, RALPH EDWIN, Electrical Engineer, Engineering Department, Syracuse Lighting Co., Syracuse, N.Y.

HIRT, WILLIAM ADOLPH, Chief Electrician, North Shore Electric Co., Evanston, Ill.

JARVIS, EDWARD A., Patent Attorney, 231 Broadway, New York City; res., 19 Sharp Avenue, Port Richmond, N. Y.

JENNINGS, NATHAN LOUIS, Superintendent of Machinery, Colorado School of Mines, Golden, Colo.

JOHNS, GEORGE MCDERMON, Assistant Engineer, St. Louis Water Department, 34 E. Grand Ave., St. Louis, Mo.

JUTTON, HENRY WILLIAM, Nernst Lamp Department, Canadian Westinghouse Co., Ltd., Hamilton, Canada.

KELLY, JOHN ZERN, Salesman, Westinghouse Electric & Manufacturing Co., 165 Broadway, New York City.

KING, THOMAS, Teacher, Ulladulla, New South Wales, Australia.

KING, WARREN D., Manager, Municipal Light Department, Peabody, Mass.

KLINE, HERBERT WEST, Superintendent of Equipment, Rocky Mountain Bell Telephone Co., Salt Lake City, Utah.

KRAPS, LEO JACOB, Repair Electrician, Sierra and San Francisco Power Co., Vallecito, Cal.

LANGE, EDWARD CARL, National Tube Co.; res., 302 East Church St., Kewanee, Ill.

LORENTZ, FLOYD SHELDON, Electrical Engineer, Construction Dept., Keating Gold Mining Co., Radersburg, Montana.

LUCAS, FRANCIS FERDINAND, Division Maintenance Inspector, Southern Bell Telephone and Telegraph Co., Atlanta, Ga.

MANSFIELD, ALBERT PRESTON, General Electric Company, West Lynn; res., Lynnfield, Mass.

McCLAIN, RAYMOND DUNWOODY, Construction Foreman, with J. E. Sirrine, Greenville, S. C.

McCOY, HUGH ANGUS, Division Superintendent, New England Telephone and Telegraph Co., Lowell, Mass.

MILLER, WESLEY CUMMINGS, JR., Engineer of Power Stations, Southern Pacific Co., 1110 Flood Bldg., San Francisco, Cal.

MORSE, ALBERT WITHERS, Chief Draftsman, Motive Power & Car Dept., Grand Trunk Pacific Railway, Rivers, Minatoba.

MORTENSEN, NIELS LAURIDS, Electrical Engineer, Cutler-Hammer Mfg. Co.; res., 114 10th Street, Milwaukee, Wis.

MUNNING, AUGUST P., General Sales Agent, Cutler-Hammer Manufacturing Co., Room 1483, 50 Church St., New York City.

MURPHY, JAMES SCOTT, Manager, Preston Light and Power Co., Terra Alta; res., 108 Beverly Ave., Morgantown, W. Va.

O'REILLY, THOMAS WILLIAM, 401 Merchant Trust Building; res., 2170 Hobart Blvd., Los Angeles, Cal.

OVITT, FAY HENRY, Superintendent, Northern Telephone Co., Enosburg Falls, Vt.

OWEN, ALEXANDER CAY, Operator, Electric Power and Light Dept., Dunedin City Corporation, Dunedin, N. Z.

PACE, EDGAR J., Electrical Engineer, Buckeye Engine Co., Salem, Ohio.

PATTERSON, RALPH E., Superintendent, Water and Light Plant, Tonkawa, Oklahoma.

PETRIE, JAMES REID, Mechanical and Electrical Engineer, Empresa de Corrente Electrica, Mazatlan, Mexico.

RAKESTRAW, CLAUDE NORRIS, Assistant Engineer, Telluride Power Co., Provo, Utah.

REID, LON GRENARD, Assistant Cable Wire Chief, Chicago Telephone Co., Chicago, Ill.

ROBINSON, ROY MILSON, Chief Electrician, Topeka State Hospital, Topeka, Kansas.

ROBLES, CARLOS ENRIQUE, Manager, Cartago Light & Power Co., Cartago, Costa, Rica.

ROYER, THOMAS JEFFERSON, Steam Electric Operator, Los Angeles Aqueduct, Aqueduct, Cal.

SAGE, MERTON W., 4th Assistant Examiner, Patent Office, Washington, D. C.

SCHNEEBERGER, GROVER BOYD, Operator, Cleveland Electric Illuminating Co.; res., 2519 Cedar Ave., Cleveland, Ohio.

SEYBOLD, ROSCOE, Commercial Engineer, Westinghouse Electric & Mfg. Co., Pittsburg; res., 313 Barnes St., Wilkinsburg, Pa.

SKOOG, SIDNEY PAUL, Electrician, California Wine Association; res., 536 Ashbury St., San Francisco, Cal.

SNYDER, WILLIAM THOMAS, Superintendent Electrical Department, National Tube Co., McKeesport, Pa.

STAFFELBACH, WILLIAM ARTHUR, Sub-Station Operator, Commonwealth Edison Co.; res., 3752 Sheffield Ave., Chicago, Ill.

STAHL, WERNER WILLIAM, Plant Department, Rocky Mountain Bell Telephone Co., Salt Lake City, Utah.

TAYLOR, DAVID BRIER, Assistant Superintendent, Electrical Department, Troy Gas Company, Troy, New York.

THOMAS, GEORGE BUNTON, Instructor, Massachusetts Institute of Technology, Boston, Mass.

TOWNSEND, HARRY DEMAREST, Assistant to Superintendent Electrical Dept., Carnegie Steel Co., Youngstown, O.

VAUGHN, FRANCIS ARTHUR, Electrical Engineer, Lighting Department, Milwaukee Electric Railway & Light Co., Milwaukee, Wis.

WALDENFELS, FREDERICK GRANT, Chief Electrical Inspector, Chicago Board of Underwriters, 159 La Salle St., Chicago, Ill.

WALSH, THOMAS J., Engineer, Stone & Webster Engineering Corporation, Houghton, Mich.

WHITNEY, ERLE FRANCIS, Sales Agent, General Electric Co., 609 Colman Bldg., Seattle, Wash.

WILLIS, FLOREN LE ROY, Chief Electrician, American Smelting & Refining Co., Leadville, Colorado.

WILSON, HUGH MONROE, Vice President, McGraw Publishing Co., 239 West 39th St., New York City.

WOLFRUM, CARL ADIEN, Superintendent, Telluride Power Co., Grace, Idaho.

WORTMAN, CLARENCE, Engineer, Home Telephone Co., 333 Grant Avenue, San Francisco, Cal.

Applications for Transfer

The following Associates were recommended for transfer at the meetings of the Board of Examiners held on June 22 and July 12, 1910. Any objection to the transfer of these Associates should be filed at once with the secretary.

Recommended June 22, 1910.

LEWIS L. TATUM, Assistant Chief Engineer, Cutler-Hammer Manufacturing Company, Milwaukee, Wis.

JOHN B. INGERSOLL, Chief Electrical Engineer, Spokane and Inland Empire Railroad Company, Spokane, Wash.

ARTHUR H. TIMMERMAN, Chief Engineer, Wagner Electric Manufacturing Company, St. Louis, Mo.

OLIVER C. SPURLING, Plant Engineer, Western Electric Company, Hawthorne, Ill.

L. FREDERIC HOWARD, Electrical Engineer, Union Switch and Signal Company, Swissvale, Pa.

ARTHUR SIMON, Electrical Engineer, Cutler-Hammer Manufacturing Company, Milwaukee, Wis.

Recommended July 12, 1910.

NATHANIEL A. CARLE, Consulting Engineer, Seattle, Wash.

FRANCIS A. VAUGHN, Consulting Electrical Engineer, Vaughn and Meyer, Milwaukee, Wis.

WILLIAM H. POWELL, Electrical Engineer, Allis-Chalmers Company, Milwaukee, Wis.

Applications for Election

Applications have been received by the secretary from the following candidates for election to the Institute as Associates; these applications will be considered by the Board of Directors at a future meeting. Any member or Associate objecting to the election of any of these candidates should so inform the secretary before August 25, 1910.

9604 Deutsch, Simon, Chicago, Ill.
9605 Ebmeier, H. W., Cincinnati, O.
9606 Riddle, D. W., St. Louis, Mo.
9607 Watson, M. B., Hamilton, Ont.
9608 Noyes, A. H., Ukiah, Cal.
9609 Rutz, E. C., Chicago, Ill.
9610 Steelman, J. C., Texarkana, Texas.
9611 Yrigoyen, P. J., Mexico City, Mex.
9612 Cahoon, W. H., Greenwich, Conn.
9613 Forbes, S. G., Gatun, C. Z.
9614 Grigsby, R.W.W., Los Angeles, Cal.
9615 Sterrett, J. A., Washington, D. C.
9616 Wrenn, H. B. P., Detroit, Mich.
9617 Bowling, V. S., Mexico City, Mex.
9618 Caird, H., Chicago, Ill.
9619 Calland, O. G., Mansfield, Ohio.
9620 Cheney, H. W., Milwaukee, Wis.
9621 Clarke, D. M., Asheville, N. C.
9622 Dubilier, Wm., Newark, N. J.
9623 Flickinger, F. G., New York City.
9624 Hadley, C. G., Brant Rock, Mass.
9625 Izant, G. W., Cleveland, Ohio.
9626 Lynch, H. B., Glendale, Cal.
9627 Pirie, J. H., Fort Dade, Florida.
9628 Popper, Eugene, Butte, Mont.
9629 Stack, G. E., Schenectady, N. Y.
9630 von Kando, K., Vado Ligure, Italy
9631 Brown, Leo, Hamilton, Ont.
9632 Offutt, M. W., Schenectady, N. Y.
9633 Peterson, John, Portland, Ore.
9634 Hutton, D., J., Mexico City, Mex.
9635 Leonard, Francis E., Chicago, Ill.
9636 Haynes, Delos G., Washington, D.C.
9637 Newill, G. E., Inde Durango, Mex.
9638 Kunzmann, Henry, Fort Mills, P. I.
9639 Arnold, Anothony B., Boston, Mass.
9640 Carlisle, John L., St. Louis, Mo.
9641 Huch, Otto F., St. Louis, Mo.

9642 Demmert, Otto, Bayonne, N. J.
9643 Alexander, Frank E., Butte, Mont.
9644 Hartwell, E. F., Homestead, N. J.
9645 Therrell, D. M., Atlanta, Ga.
9646 Pagano, C. J., Chicago, Ill.
9647 Albert, J. C., Los Angeles, Cal.
9648 Donald, James, Mooresville, N.C.
9649 Hoon, C. L., Brown, Cal.
9650 Newton, Geo. J., New York City.
Total 47.

Students Enrolled June 29, 1910

3726 Beebe, L. H., Penn. State College.
3727 Brown, R. E., Lehigh University.
3728 Crocker, R. W., Univ. of Maine.
3729 Dodge, R. L., Mass. Inst. Tech.
3730 Duncan, A. C., Lewis Institute.
3731 Dutt, J. C., Lewis Institute.
3732 Metcalfe, V. E., Univ. of Colorado.
3733 Moyer, L. M., Univ. of Wash.
3734 Rohde, W. C. F., Univ. of Wis.
3735 Smith, G. H., Univ. of Wash.
3736 Sullivan, D. L., Mass. Inst. Tech.
3737 Torrey, L. E., Univ. of Cal.
3738 Lufkin, F. R., Mass. Inst. Tech.
3739 Watson, W. C., Worcester Poly. Inst.
3740 Ferre, E. C., Univ. of Pittsburg.
3741 Meredith, H. C., Penn. State Coll.
3742 Hippler, H. A., Mass. Inst. Tech.
3743 Burgner, H. T., Univ. of Illinois.
3744 Chinlund, J. F., Univ. of Illinois.
3745 Greenough, W. C., Worcester Poly. Inst.
3746 Childs, R. B., Colorado College.
3747 Ollivera, Jose, Cornell Univ.
3748 Coinre, L. W., Kan. State Agr. Col.
3749 Fisher, A. W., Penn. State College.
3750 Jones, L. M., Syracuse University.
3751 Bennett, L. W., New Hampshire, Coll.
3752 Sullivan, A. H., Univ. of Nebraska.
3753 Anderson, O. V., Univ. of Minn.
3754 Bastian, H. S., Bucknell Univ.
3755 Brubaker, C. N., Bucknell Univ.
3756 Case, G. F., Bucknell Univ.
3757 Decker, R. C., Bucknell Univ.
3758 Fagley, G. H., Bucknell Univ.
3759 Fairchild, A. C., Bucknell Univ.
3760 Hallock, H. F., Univ. of Mich.
3761 Huston, A. J., Bucknell Univ.
3762 Jackson, W. C., Lehigh Univ.
3763 Johnson, J. C., Lewis Institute.
3764 Keeler, H. E., Univ. of Mich.
3765 Kiehle, G. S., Univ. of Michigan.
3766 Martin, S. H. Lewis Institute.
3767 McDonnell, E. A., Univ. of Mich.
3768 Norquist, G. H., Univ. of Mich.
3769 Roser, J. O., Bucknell University.
3770 Roush, J. L., Highland Park Coll.
3771 So Relle, A. W., Clarendon, Texas.
3772 Wetterborg, H. A., Univ of Ore.
3773 Armstrong, E. A., Mich. Agr. Coll.
3774 Hobbs, G. W., Mich. Agr. Coll.
3775 Kincaid, C. W., Univ. of Pittsburg.
3776 Shaw, J. L., Mich. Agr. College.
Total 51.

Standardization Rules Suggested Amendments

(*Full text of existing Standardization Rules, may be found in any one of the following publications*: *Year Book for* 1910, *pp.* 66; *Part II of the* TRANSACTIONS *for* 1907, (*Vol. XXVI*), *pp.* 1797; PROCEEDINGS *for July* 1907, *pp.* 1077; *or a separate pamphlet containing the Standardization Rules may be obtained from Institute headquarters,* 33 *West* 39*th Street, New York.*)

At the recent annual convention it was voted that the amendments to the Standardization Rules as proposed by the Standards Committee be submitted to the membership in order that criticisms and suggestions might be submitted for the consideration of the committee. As the date for the receipt of these suggestions was fixed for August 1 by the resolution adopted by the convention, it was necessary that a special circular be prepared and distributed so that members might send in their contributions during July. The chairman of the Standards Committee, however, wishes it understood that the committee will be pleased to receive suggestions at any time, which will be discussed by the committee at future meetings, with a view to incorporation in the Standardization Rules whenever acceptable. It is the purpose of the committee to keep these rules up to date, and to accord with existing prac-

tice as far as possible. Communications concerning these rules should be sent to the Secretary, 33 West Thirty-ninth Street, New York City, for the attention of the committee.

* Asterisks denote changes.

|| Marginal lines denote additions.

|| **6a** Two-phase. A term implying the supply of power through two circuits carrying alternating currents which differ 90° in phase.

9 An ALTERNATOR or ALTERNATING-CURRENT GENERATOR produces
* alternating currents, either single-
* phase or polyphase.

|| **9a** A COMPENSATED ALTERNATOR is an alternator which automatically compensates for the drop in voltage in its armature, or in its armature and the line.

|| **9b** A SYNCHRONOUS COMPENSATOR is a synchronous machine, running either idle or under load, whose full excitation may be varied so as to modify the power-factor of the circuit, or through such modification, to influence the voltage of the circuit.

|| **11a** AN INDUCTOR ALTERNATOR is an alternating-current generator in whose armature windings the field magnetic flux pulsates but never reverses.

|| **11b** AN INDUCTION GENERATOR is a machine similar to an induction motor but driven as an alternating-current generator.

***20** *d.* A FREQUENCY-CHANGER converts from an alternating-current system of one frequency to an alternating-current system of another frequency, with or without a change in the number of phases or in voltages.

|| **21a** A ROTOR is a rotating member of a machine.

|| **21b** A STATOR is a stationary member of a machine.

|| **21c** EQUALIZING RINGS are rings connected to equipotential points of multiple-wound armatures to equalize the voltage between brushes.

|| **23a** A PRIMARY WINDING is that winding of an induction motor or of a transformer which receives power from an external source.

|| **23b** A SECONDARY WINDING is that winding of an induction motor or of a transformer which receives power from the primary by induction.

Note: The terms " High-tension winding " and " Low-tension winding " are suitable for distinguishing between the windings of a transformer where the relations of the apparatus to the source of power are not involved.

***26** (*a*) COMPENSATOR POTENTIAL
* REGULATORS, also called Contact
* Regulators, in which a number of
* turns of one of the coils are ad-
* justable.

***29** *d.* REACTANCE COILS, sometimes
* called choke coils, are a form of stationary induction apparatus used to produce reactance or phase displacement.

|| **29b** *e.* A TRANSFORMER BALANCER is an auto-transformer for dividing a voltage in constant proportions, and usually into two equal portions.

|| **29c** *f.* AN INDUCTION STARTER is a device used in starting induction motors, converters, etc., when they are started by voltage control, consisting of an auto-transformer in connection with a suitable switching device.

|| **29d** *g.* A LEAKAGE REACTANCE is that portion of the reactance of any induction apparatus which is due to stray flux.

F. INSTRUMENTS.

|| **49a** A SYNCHRONOSCOPE is a synchronizing device which, in addition to indicating synchronism, shows whether the machine to be synchronized is fast or slow.

|| **49b** A VOLTMETER COMPENSATOR is a device used in connection with a voltmeter to reduce its reading by the amount of the line drop, and thus causing it to indicate the

voltage delivered at the distant end, or at any other predetermined point of the line.

49c A WATTHOUR METER is an instrument for registering total watt-hours. This term is to be preferred to the term "integrating wattmeter".

49d RECORDING AMMETERS
RECORDING VOLTMETERS
RECORDING WATTMETERS
are instruments which record upon a time-chart the values of the quantities they measure.

78a *b.* INDICATING METERS should be rated according to their full-scale reading of volts, amperes, or watts (at unity power-factor in wattmeters).

78b *c.* WATTHOUR METERS should be rated by their power delivery at rated volts and amperes at unity power-factor.

C. EFFICIENCY.

(I) *DEFINITIONS.*

84 The EFFICIENCY of an apparatus is the ratio of its output to its input. The output and input may be in terms of watt-hours, watts, volt amperes, amperes, or any other quantity of interest, thus respectively defining energy efficiency, power efficiency, apparent-power efficiency, current efficiency, etc. Unless otherwise specified, however the term efficiency is ordinarily assumed to refer to power efficiency.

When the input and output are expressed in terms of the same unit, the efficiency is a numerical ratio, otherwise it is a physical dimensional quantity.

109 The speed-time curves can be plotted automatically by belting a small separately excited generator (say 1/10 kw.) to the generator shaft and connecting it to a recording voltmeter. When the retardation method is not feasible, the frictional losses in bearings and in windage, which ought, by definition, to be included in determining the efficiency, may be *excluded.

(*J*) PHASE-DISPLACING APPARATUS.

181 In APPARATUS PRODUCING PHASE DISPLACEMENT as, for example, synchronous compensators, exciters of induction generators, reactors, condensers, polarization cells, etc., the efficiency should be understood
* to be the energy efficiency.

216 CONDITION OF APPARATUS TO BE TESTED. Commercial tests should, in general, be made with the completely assembled apparatus and not with individual parts. The apparatus should be in good condition and high-voltage tests, unless otherwise specified, should be applied before the machine is put into commercial service, and should not be applied when the insulation resistance is low owing to dirt or moisture. High-voltage tests should, in general, be made at the temperature assumed under normal operation. High-voltage tests considerably in excess of the normal voltages to determine whether specifications are fulfilled are admissible on new machines only. Unless otherwise agreed upon, high-voltage tests of a machine should be understood as being made at the factory.

308 TRANSMISSION CIRCUITS. In alternating-current constant-potential transmission circuits, the following average voltages are recommended.

6,600	11,000	22,000	33,000
44,000	66,000	88,000	110,000

317 When white lights are used a light turned on should denote danger, such as "switch closed" or "circuit alive"; while the light out should denote safety, such as "switch open," or "circuit dead." Low-efficiency lamps should be used on account of their lesser liability to accidental burn out.

APPENDIX C. PHOTOMETRY AND LAMPS.

341 CANDLE-POWER. The luminous intensity of sources of light is expressed in candle-power. The unit of candle-power should be derived from the standards maintained by the National Bureau of Standards
* at Washington, D. C. The Hefner
* is 0.90 of this unit. In practical
* measurements seasoned and care-
* fully standardized incandescent lamps are more reliable and accurate than the primary standard.

342 CANDLE-LUMEN. The total flux of light from a source is equal to its mean spherical intensity multiplied by 4π. The unit of flux is called
* the lumen. A lumen is the $\frac{1}{4\pi}$th
* part of the total flux of light
* emitted by a source having a mean spherical intensity of one candle-power. A hefner-lumen is 0.90 lumen.

*346 The EFFICIENCY OF ELECTRIC
* LAMPS is properly stated in mean
* spherical candle-power per watt,
* and preferably in lumens per watt,
* at lamp terminals.

*354 The TOTAL FLUX of light in lumens emitted by a lamp $= 4\pi \times$ mean horizontal candle-power $\times$ spherical reduction-factor.

Section Meetings

ATLANTA

The Atlanta Section held its regular monthly meeting in the Equitable Building, Atlanta, on June 14, 1910. After a discussion of various business matters relating to local affairs, Mr. E. P. Peck, in charge of the laboratory of the Georgia Railway and Electric Company, read a paper on *The Test and Operation of a 2,000 kw. Frequency Changer Set.* The paper was discussed by Messrs. H. P. Wood, A. M. Schoen, F. G. Sidell, and M. E. Bonyun.

BALTIMORE

At the meeting of the Baltimore Section on June 15, 1910, the following officers were elected for the ensuing year: Chairman, J. B. Whitehead, secretary, L. M. Potts; executive committee, H. H. Seabrook, T. A. Cross, H. Lomas, A. S. Loizeaux, J. B. Scott. A paper was then presented by Dr. J. B. Whitehead, on *The Losses in High Tension Lines.*

FORT WAYNE

The annual meeting of the Fort Wayne Section was held in the home of Chairman E. A. Wagner on the evening of June 9, 1910. The following officers were elected for the ensuing year: Chairman, E. A. Wagner; vice-chairman, J. J. Kline; secretary, J. V. Hunter. In addition to the above named officers the following were elected members of the executive committee: A. L. Hadley, P. C. Morganthaler, and J. H. Hessin. Aside from the business on the calendar the meeting was intended to be a purely social affair, and at the conclusion of the routine work the members were entertained by Mr. Wagner.

CHICAGO

A joint meeting of the Chicago Section with the Electrical Section of the Western Society of Engineers was held in Chicago on June 7, 1910. Mr. F. Darlington, of Pittsburgh, Pa., was the guest and speaker at this meeting, and presented a paper entitled *Economic Considerations Governing the Selection of Electric Railroad Apparatus.* The paper was discussed by Messrs. W. L. Abbott, G. T. Seely, W. B. Jackson, A. P. Jenks, E. N. Lake, George H. Lukes, A. E. Bement, and Clarence Renshaw.

MADISON, WISCONSIN

The final meeting of the Madison Section for the season of 1909-1910 was held in the engineering building of the University of Wisconsin on June 9, 1910, with Mr. H. B. Sanford presiding in the absence of Chairman Collbohm. A committee was appointed to draw up a constitution and by-laws, the committee to report at the first

meeting in the fall. The following papers were then presented: *Operating and Operators in Chicago*, by W. H. Beasley, of the North Shore Electric Company; *A Method of Determining the Adequacy of an Electric Railway System*, by R. W. Harris, electrical engineer with the Wisconsin Tax and Railroad Commission. Thirty members were present.

Mexico

The members of the Mexico Section met in the Cafe Paris, Mexico, on June 9, 1910. Chairman Leonarz announced that Mr. W. A. Ferguson had handed in his resignation as secretary, on account of stress of business, and Mr. Gustavo Lobo was elected his successor. Mr. Leonarz read a paper entitled *Some Remarks on Calculations of Electromagnetical Apparatus*. Owing to the lateness of the hour discussion of the paper was postponed until the next meeting.

Philadelphia

The Philadelphia Section held its annual meeting, which was also the occasion of its annual dinner, at the Engineers' Club, Philadelphia, on June 13, 1910. The election of officers resulted as follows: Chairman, C. I. Young; secretary-treasurer, H. F. Sanville; assistant secretary, L. J. Costa; managers, George R. Green, St. John Chilton, and J. L. Kilpatrick. After the dinner addresses were made by Messrs. Paul M. Lincoln, C. I. Young, R. B. Owens, E. L. Northrup, H. C. Snook, H. A. Hornor, George R. Green, C. W. Pike, Dr. George A. Hoadley, and Mr. Ralph W. Pope, Secretary of the Institute, who was a guest at the dinner.

Pittsfield

The final meeting of the Pittsfield Section for the season of 1909–1910 was held in the Hotel Wendell, Pittsfield, on June 9, 1910. A large number of members were in attendance, and heard with much interest descriptions of foreign power plants and manufacturing practice in foreign countries by Messrs. W. S. Moody, G. J. Brimson, and H. W. Tobey.

Mr. Tobey, the retiring chairman, opened the meeting with a few brief remarks, and then announced the result of the election of officers for next season. These were as follows: Chairman, S. H. Blake; secretary, W. C. Smith; executive committee, S. H. Blake, W. C. Smith, and G. Faccioli; advisory committee, C. C. Chesney, J. J. Frank, C. A. Kelsey, H. P. Ball, and H. W. Tobey; chairman membership committee, L. F. Blume; chairman entertainment committee, E. Stanley.

The meeting was then turned over to Mr. Moody, who presided for the remainder of the evening. After the reading of the annual report, which showed a healthful growth in membership and interest during the year, Mr. Moody introduced Mr. Tobey, who spoke on "Italian Power Plants." A description was given of some of the more important plants in Northern Italy, with special reference to the Toci system, which supplies Novara and the surrounding country, and the Adamello system, which supplies the city of Milan. Many interesting points and facts were brought out by Mr. Tobey, and the talk was illustrated throughout by lantern slides.

Mr. Moody then introduced Mr. G. J. Brimson, who spoke at length on his experiences in India. Mr. Brimson was employed by the General Electric Company to install a large amount of apparatus in that country, and in all spent about three years there. He described the various lines of work with which he came in contact, illustrating his talk with lantern slides. Many of these showed conditions which had to be met, and the class of labor and officials connected with the work. In speaking of the labor, Mr. Brimson stated that many of the workmen he employed for assembling the apparatus and putting it into operation received but ten to 12 cents per day, while laborers of the cheaper class receive but from one to two cents per day, in

American money. Iron of all kinds is in great demand, as shown by the fact that after the construction work had been completed, old iron cans and pails were auctioned off at from 50 to 60 cents apiece, while small bolts and pieces of iron brought from 10 to 20 cents each.

The last speaker, Mr. Moody, gave an outline of his experiences during his recent trip abroad, with special reference to those in Germany. He gave a clear idea of manufacturing conditions and types of apparatus now found in that country. In general, the workmen are equal in ability to those of our own country, to turn out apparatus quickly and well. Labor is considerably cheaper, averaging, perhaps, from 35 to 40 per cent of what we are accustomed to pay for a similar class of work. There is a lack, however, in standardization as we know it, almost every piece of apparatus being different from that which preceded it. This prevents turning out duplicates in large quantities, and tends largely to offset the saving due to lower cost of labor. In conclusion Mr. Moody described many interesting customs and habits of German workmen.

San Francisco

The regular meeting of the San Francisco Section was held on June 24, 1910, in the Home Telephone Company Building, San Francisco. The election of officers for the year resulted as follows: Two-year term, S. G. McMeen and H. A Lardner; one-year term, W. A. Hillebrand; hold-over officers, C. W. Burkett and S. J. Lisberger. Following the executive business, Mr. L. R. Jorgensen read a paper entitled *Possible Improvements in Steam Plant Economy*. The attendance was considerably smaller than usual, many members being absent for the summer season.

Schenectady

At the meeting of the Schenectady Section held on April 26, 1910, Mr. Frederick E. Ives, of Philadelphia, gave a lecture on color photography. Mr. Ives was the first to successfully reproduce colors of nature by means of photography, and his lecture, which was illustrated by many pictures thrown on a screen by a triple-lens lantern, marked one of the most interesting meetings of the season. One of Mr. Ives most recent developments is the standardization of the process of readily and cheaply making color transparencies by absorption. This process, used in connection with his new tripak camera, enables anyone to make pictures correct in color in all details. The construction of this camera, as well as all the methods used in Mr. Ives process, was fully explained. The attendance numbered about 400 members and their friends.

On the evening of May 10 the Section brought its work for the season of 1909–1910 to a close by its first annual banquet. About 200 members were present to enjoy the tempting menu and entertainment provided by the entertainment committee. The Edison Club orchestra, of 15 pieces, and the Institute quartette, were largely instrumental in the success of the banquet. A brief report of the year's work was submitted by Chairman M. O. Troy. The only business transacted was the passing of a resolution to send to the local congressional representative in Washington a request urging support in behalf of the Weeks Bill, which provides for the extension and protection of the Appalachian forest preserves. The entertainment committee consisted of Messrs. A. B. Lawrence, chairman, V. E. Goodwin, W. F. Drysdale, and A. L. Atkinson.

Seattle

Instead of the regular meeting for June, the Seattle Section gave a dinner and dance at the faculty clubhouse of the University of Washington, Seattle. After the dinner members of the faculty of the university showed the visitors through the new electrical laboratories. Mr. John Harisberger gave a short talk

regarding the San Francisco meeting of the Institute on May 5, 6 and 7, 1910, at which he was present as a representative of the Seattle Section.

Branch Meetings

IOWA STATE COLLEGE

A meeting of this Branch was held on March 16, 1910. Professor Adolph Shane gave a talk on *Investigations of Transformer Regulation*, in which he described the various methods of determining transformer regulation and of their probable accuracy.

On April 6 nearly 350 members and students gathered to hear a lecture by Professor L. B. Spinney. on "The Principle of the Gyrostat and Its Applications." Professor Spinney exhibited a number of gyrostats, and illustrated their workings under different conditions. Lantern slides were shown to illustrate the gyrostatic action of the earth, and a number of other familiar objects into which gyrostatic action enters were also shown on the screen. In conclusion Professor Spinney explained the use of the gyrostat in the Brennan monorail car, exhibiting a model of the car and showing its action.

During the afternoon and evening of April 13 the Branch held its second annual electrical show. Extensive preparations had been made previously, and everything was in readiness at the opening hour. It was estimated that about 4,000 people attended the show, many of whom were from out of town, a large delegation coming from Des Moines. The various exhibits were located in the engineering hall and engineering annex, nearly 20 rooms being given over for the occasion, with a number of exhibits in each. Domestic appliances attracted great attention, and the show was a decided success in every way.

The meeting of May 4 was devoted to a discussion of the National Electric Code, which was reviewed by Messrs. J. M. Mercer. Chatterton, Shane, Pullen, Cole, and Yocum.

LEWIS INSTITUTE

The close of the third successful season of the Lewis Institute Branch was marked by a dinner held on June 3, 1910, which was attended by 270 members and guests. Officers for the ensuing year were elected as follows: Chairman, J. C. Johnson, of the Commonwealth Edison Company; vice-chairman, George Strachan, electrical engineer, City of Chicago; secretary, A. H. Fensholt, Lewis Institute. Following the dinner Mr. R. M. McCormick, president of the Board of the Sanitary District, spoke on the subject, "Manufacture and Use of Electric Power."

PENNSYLVANIA STATE COLLEGE

At the last meeting of this Branch for the season of 1909–1910, held on May 25, 1910, the following officers were elected to serve for the first three months of the next year. Chairman, C. M. Wheeler; vice-chairman, H. L. Mathers; treasurer, O. C. Himberger; secretary, J. M. Spangler; marshal, T. W. Powell.

Personal

MR. H. A. LARDNER, manager of J. G. White and Company's San Francisco office, is convalescing from a prolonged siege of typhoid fever.

MR. JOHN C. PARKER, electrical engineer of the Rochester (N. Y.) Railway and Light Company, was married on June 21 to Miss Elizabeth Brooks at Rochester.

MR. M. ULMER has left Messrs. Schondube and Neugebauer and is again connected with the Mexican Light and Power Company Ltd., Mexico City.

MR. W. C. KENNEDY, recently with the Cutler-Hammer Manufacturing Company at their Milwaukee works, is

now in the Philadelphia office of the same Company.

MR. E. V. EARDLEY, formerly with the General Electric Company at Boston, has resigned to take a position as electrical engineer with the Knight Power Company, Salt Lake City, Utah.

MR. GEORGE B. ROBERTS having completed the engineering and construction work on the Home Telephone Company's plant at St. Joseph, Mo., resigned on July 1, 1910.

PROFESSOR A. M. BUCK has left the New Hampshire College to take charge of the electrical engineering department at the Clarkson School of Technology, Potsdam, N. Y.

MR. WILLIAM MARSHALL, a Cornell University student, has accepted a position in the engineering department of the Stromberg-Carlson Telephone Manufacturing Company, Rochester, N. Y.

MR. LUTHER W. HAWLEY has resigned as science instructor in the Braintree, (Mass.), High School to accept a position as assistant examiner in the U. S. Patent Office, Washington, D. C.

MR. HARRY W. HOUGH has left the Norfolk and Southern Railway Company to join the engineering department of the Cleveland Electric Illuminating Company of Cleveland, Ohio.

MR. R. B. BRYANT, formerly with the Southwestern Telephone and Telegraph Company, has accepted the position of manager of the Ozark Electric Light and Power Company, Ozark, Ark.

MR. V. L. BENEDICT, for several years connected with the General Electric Company, has resigned from its Los Angeles office to become manager of the Los Angeles Fire Alarm Company.

MR. E. M. ASHWORTH, who has been with the Canadian General Electric Company for the last 10 years, has been appointed assistant to the managing engineer of the Toronto Hydroelectric System.

MR. REID JONES, until lately a student at Cornell University, Ithaca, N. Y., has taken charge of the engineering end of the San Antonio Water Supply Company of San Antonio, Texas.

MR. P. H. AFFOLTER, until recently inspector for the Laramie Electric Company, Laramie, Wyo., has accepted the position of superintendent of the Brush Light and Power Company, of Brush, Colo.

MR. S. E. GATES was appointed on June 1 agent in charge of the Spokane office of the General Electric Company. Mr. Gates was formerly in the power and mining department of the Portland office.

MR. GEORGE R. WADSWORTH recently severed his connections with public service work in Boston to accept the position of assistant to the president of the Peerless Motor Car Company, Cleveland, Ohio.

MR. E. D. DOYLE, of Champaign, Ill., a former student at the University of Illinois, is now in the testing department of the General Electric Company at Schenectady. His address is 203 Seward Place, Schenectady, N. Y.

MR. L. G. GRESHAM, formerly in the small motor department of the General Electric Company, New Orleans, is now associated with H. M. Byllesby and Company, Chicago, as power expert of their new business department.

Mr. William C. Getz, of the Signal Service at Large, having completed the installation of the target range signaling system at Fort Riley, Kansas, has left for Port Snelling, Minn., to install a telephone system at that post.

Mr. Evan J. Edwards, formerly instructor in electrical engineering at the Massachusetts Institute of Technology, Boston, is now in the engineering department of the National Electric Lamp Association, Cleveland, Qhio.

Mr. A. F. Norcross, of Minneapolis, who has been with the Engineering Supervision Company, 45 West 34th Street, New York City, for a number of months, has succeeded Mr. Hubert E. Collins as general manager of the company.

Mr. R. H. Johnston, for several years advertising manager of The White Company, has been appointed manager of the New York branch office of the company, with headquarters at Broadway and 62nd Street, New York City.

Mr. W. M. N. Eglinton has resigned as chief constructing engineer and manager of the Compania Electrica de Concepcion, and has become associated with the firm of A. Lincoln Eglinton and Company, 43 Exchange Place, New York City.

Mr. Gerald Deakin has been appointed engineer of the Home Telephone Company of San Francisco, the Home Telephone Company of Alameda County, and the Bay Cities Home Telephone Company, with headquarters in San Francisco, Cal.

Mr. James N. Baker has resigned as motor salesman in the Louisville, Ky. office of the Westinghouse Electric and Manufacturing Company, to accept the position of electrical engineer with R. Hoe and Company, New York.

Mr. Austin Burt, general superintendent of the Citizens' Gas and Electric Company, Waterloo, Iowa, has been elected president of the Iowa District Gas Men's Association. Mr. Burt served last year as vice-president of the association.

Mr. R. H. Klauder, who for the last 18 months has been chief engineer of the United Water Improvement Company, Philadelphia, has resigned to take up work in the sales department of the Natural Carbon Company, Cleveland, Ohio.

Mr. M. W. Pullem has given up his position as instructor in electrical engineering at the Iowa State College to take a post graduate course in electrical engineering in the Massachusetts Institute of Technology beginning in the fall.

Mr. H. W. Matthews, who for a number of years has been in the erecting department of the Westinghouse Electric and Manufacturing Company at Pittsburg, has been transferred to the New York office of the same department at 510 West 23rd Street.

Mr. Charles C. Clark recently resigned from the transformer department of the Westinghouse Electric and Manufacturing Company to take a position as salesman for Messrs. Kilmer and Pullen, Canadian agents for the Swedish General Electric Company.

Mr. George B. Foster has been appointed Chicago sales manager for the Wilson Engine Company, and will be located in the Fisher Building, Chicago. Mr. Foster will represent the company in the sale of their apparatus in the Chicago district.

Mr. C. M. Garland, for several years instructor in mechanical engineering at the University of Illinois, has accepted a position with the Camden

Iron Works, at Camden, N. J. His mailing address is 104 Linden Avenue, Collingswood, N. J.

Mr. Meyer Barnert, who for several years has been connected with the Schenectady and Atlanta offices of the General Electric Company, has just resigned to accept a position in the power department of the Empire District Electric Company at Joplin, Mo.

Mr. C. A. Tozer, formerly station superintendent with the Telluride Power Company at their Ames Station, is now located at Spencerport, N. Y., with the Empire Engineering Corporation as assistant superintendent of the Barge Canal Contract Company.

Mr. E. W. Stevenson, electrical engineer of the Hazard Manufacturing Company, Wilkesbarre, Pa., sailed for England on the White Star Liner Adriatic on Wednesday, July 27. Mr. Stevenson is going abroad for a seven weeks' vacation, and is accompanied by Mrs. Stevenson.

Mr. L. L. Gaillard, general manager of The New England Engineering Company, has removed the offices of the engineering department of the company from 113 Church Street, New Haven, Conn., to the Hudson Terminal Building, 50 Church Street, New York City.

Mr. John W. Dorsey has accepted the appointment of lecturer in electrical and mechanical engineering at the University of Manitoba, Winnipeg, Manitoba, Can., having resigned the chair of electrical engineering at the Clarkson School of Technology Potsdam N. Y.

Mr. Leon I. Thomas resigned on June 1 as superintendent of the factory of the Radio Telephone Company, Newark, N. J., to associate with Mr. F. Lowenstein, consulting engineer, 117 Nassau Street, New York City, in the design and construction of wireless apparatus.

Mr. H. G. Nicholls, president, Factory Products Limited, Toronto, Ont., announces the appointment of his company as sole agents in Canada, for the General Electric Company, of London, England, the Stothert and Pitt Company, Bath, England, and Pirelli Limited, of Milan, Italy.

Dr. John F. Kelly, president of the Telelectric Company of Pittsfield, Mass., was recently awarded the John Scott Medal in recognition of his inventions and improvements in piano players. The award was made on recommendation of the Franklin Institute, of Philadelphia.

Mr. J. V. B. Duer, until recently with the Long Island Railroad Company as electrical inspector, has been appointed foreman of motormen with the Pennsylvania Tunnel and Terminal Railroad Company, with headquarters at the Pennsylvania Station, 8th Avenue and 31st Street, New York City.

Mr. W. E. Harkness, who for several years has been identified with the Western Electric Company in the development of train dispatching, has become associated with the United States Electric Company, of New York City, in connection with telephone, telegraph and selective equipment.

Mr. J. Hermann, formerly with the Potosina Electric Company, San Luis Potosi, Mex., has resigned to accept the position of operating engineer for the Cia Hidroelectrica E Irrigadora del Chapala, S. A. Mr. Hermann's present address is Apartado 260, Guadalajara, Jal., Mexico.

Mr. K. Nishikawa, former chief electrical engineer for Saiga and Com-

pany, Osaka, Japan, has accepted the position of chief engineer of the Keisen Electric Railroad Company, a railroad connecting Kyoto and Otau, and consulting engineer for the Okayama Tramway Company, Okayama, Japan.

MR. L. C. BROOKS, for the past five years master electrician at the Boston Navy Yard, and for many years previously engaged in connection with installations on U. S. vessels, has joined the engineering staff in the industrial control department of the General Electric Company, Schenectady, N. Y.

MR. WILLS MACLACHLAN has resigned as electrical superintendent of the Welland Canal Grain elevator, department of Railways and Canals, Dominion Government, to become inspecting engineer for the Hydroelectric Power Commission of Ontario, with charge of the inter-switching station near Dundas, Ont.

MR. HARRY BINDEMANN has left the Siemens-Schuckert Werke, of Berlin, Germany, to take over the technical management of a new electrical undertaking in Madrid, Spain. This Company, the Electra, will distribute cheap electrical power in Madrid at much lower rates than has been possible with the existing steam plants.

MR. R. W. SORENSEN, of the transformer engineering department of the General Electric Company, Pittsfield, has resigned to become associate professor of electrical engineering at Throop Polytechnic Institute, Pasadena, Cal. Before taking up his duties there in the fall Mr. Sorenson will conduct for the General Electric Company a number of tests on transformers installed in the mountainous district of Colorado.

MR. E. L. BRUNDRETT resigned on May 15 as general auditor of the United Gas Improvement Company of Philadelphia to become president of the Wyandotte County Gas Company, Kansas City, Kan., vice-president of the Kansas City, Missouri, Gas Company, and general agent of McGowan, Small and Morgan. The company operates under a franchise for a supply of natural gas to Kansas City, Mo.

MR. W. C. MADDOX, formerly president of the Bateman-Garrison-Maddox Company, Champaign, Ill., and Mr. C. E. Armstrong, former general superintendent of the Cairo Railway and Lighting System, Cairo, Ill., have formed a company as engineers and manufacturers agents, with an office at 526 Woolner Building, Peoria, Ill. The firm will carry on a general engineering business and represent various manufacturers of mechanical and electrical apparatus.

MR. JEAN BART BALCOMB has opened a consulting engineering office at 1208 Title and Trust Building, 100 Washington Street, Chicago, Ill. Previously to the earthquake and fire in San Francisco Mr. Balcomb had an office in that city, during which time he was engaged on various important hydraulic and hydroelectric enterprises on the Pacific coast. Since then he has been with different corporations and municipalities in the East and middle West.

MR. FRANK KOESTER, engaged by the Guggenheim Exploration Company in connection with its various power propositions, has for some time had in hand the designing of a 12,000 kw. hydroelectric development for the American Smelting and Refining Company in connection with an extensive copper concentrating plant of the Braden Copper Company at Rancagua, Chile, S. A., with initial powerhouse equipment of three 2,000 kw. main units, and a 30-mile, 33,000-volt transmission system.

Obituary

Frederick H. Lincoln, vice-president and general manager of the Pay-Within Car Company, Philadelphia, Pa., while attempting to board a moving train at the West Philadelphia station on July 11, fell beneath the wheels and was almost instantly killed. Mr. Lincoln was born in Boston, Mass., on May 28, 1867. After three years' apprenticeship at the machinist's trade, he began his electrical career with the Thomson Houston Company in 1886. In 1888 this company started the development of its street railway system and Mr. Lincoln was transferred to the railway department, and placed in responsible charge of electric railway installations in various cities throughout the country. In 1893 he entered the employ of the People's Traction Company of Philadelphia, serving as assistant engineer during the construction period, and later having charge of the company's power plants. When all the surface roads in Philadelphia were consolidated into the Philadelphia Rapid Transit Company, in 1895, Mr. Lincoln was made superintendent of lines and cables and had charge of the redesigning and rebuilding of the company's electrical distribution system. In August 1905 he was appointed assistant general manager of the company and was placed in charge of the operation of the Market Street elevated and subway division, as well as of the maintenance of equipment of the entire system. While the elevated and subway system was being planned Mr. Lincoln was one of the party of Philadelphia Rapid Transit officers sent on a tour of Europe to study conditions in continental cities. He subsequently resigned his position to become vice-president and general manager of the Pay-Within Car Company. He was one of the inventors of the pay-within car. He took an active interest in the work of the American Street and Interurban Railway Association, and at its convention in Denver last fall was made president of the organization. Mr. Lincoln was admitted to membership in the Institute as an Associate on May 16, 1905. He is survived by a widow.

Library Accessions

Electric Motors. By F. B. Crocker and Morton Arendt. New York, Van Nostrand Co., 1910. (Gift of Authors.) Price $2.50.

Contents:—Chapter I.—Introduction. Chapter II.—Types of Motors and Advantages of Electric Drive. Chapter III.—Action of Shunt Motors. Chapter IV.—Shunt-Motor Starting Boxes. Chapter V.—Shunt-Motor Speed Control by Variation of Armature Voltage. Chapter VI.—Speed Control of Shunt-Motors by Variations of Field Current. Chapter VII.—Speed Control of Motors by Variation of Field Reluctance. Chapter VIII.—Multiple-Voltage Systems of Motor Speed Control. Chapter IX.—Direct Current Series Motors. Chapter X.—Control of Direct Current Series Motors. Chapter XI.—Compound Wound Motors. Chapter XII.—Alternating current motors—Introduction. Chapter XIII.—Synchronous Alternating-current motors. Chapter XIV.—Polyphase Induction Motors. Chapter XV.—Starting of Polyphase Induction Motors. Chapter XVI.—Speed Control of Polyphase Induction Motors. Chapter XVII.—Single-phase Induction Motors. Chapter XVIII.—Commutating Alternating-Current Motors. Chapter XIX.—Service Conditions and Applications of Electric Motors. Appendix A—Standardization Rules, Electric Motors.

International Catalogue of Scientific Literature 8th Annual issue. A-Mathematics; B—Mechanics. London, 1910. (Gift of Adams Fund.)

Machine Tool Operation for Maximum Production. By Charles Day. (Reprinted from Engineering Magazine.) n.p. n.d. (Gift of Messrs. Dodge & Day.)

National Fire Protection Association. Proceedings of 14th Annual Meeting, 1910. Boston, 1910. (Exchange.)

Polytechnic Engineer. Vol. 10, 1910. Brooklyn, 1910. (Gift of Editors.)

Société Francaise de Physique. Liste des Membres, 1909. Paris, 1909. (Exchange.)

South African Journal of Science. Vol. 6-date. Cape Town, 1910. (Exchange.)

Typical Operations No. 3. Calling attention to coöperative method of effecting economies in industrial plants. n.p. n.d. (Gift of Messrs. Dodge & Day.)

U. S. Interstate Commerce Commission. Annual Report 23d. Washington, 1910. (Exchange.)

Westinghouse Electric & Manufacturing Company. Annual Report, 1910. Pittsburgh, 1910. (Gift of Westinghouse Electric & Manufacturing Company.)

Trade Catalogues.

Crocker-Wheeler Co., Ampere, N. J. Bulletin No. 119., Direct current lighting and power generators. 15 pp.

——Bull. No. 121--Small engine type direct current generators. 7 pp.

Electric Controller & Mfg. Co., Cleveland, O., June 1910 Common Sense—a magazine of humor and commercial sociology, published by the above Company in the interests of their patrons. 24 pp.

General Electric Co., Schenectady, N. Y. Price List No. 5220—Steam and air flow meters. 6 pp.

——Bull. No. 4732—Curtis steam turbine-generator installations. 55 pp.

——Bull. No. 3919—Transformer manufacturing facilities. 23 pp.

——Bull. No. 4720—Steam and air flow meters. 11 pp.

——Bull. No. 4727—Sewing machine motors for family size machines. 7 pp.

——Bull. No. 4736—Lightning arresters for alternating currents. 27 pp.

——Bull. No. 4737—Electric hardening furnace. 7 pp.

——Bull. No. 4738—Belt driven revolving armature alternators. 4 pp.

——Bull. No. 4740—Line drop compensators type V-4 for alternating current circuits. 2 pp.

——Bull. No. 4741—Luminous arc lamps for direct current multiple circuits. 4 pp.

Holophane Co., Newark, O. Holophane Illumination, June 1910, having articles on the success of lighting by the Holophane System. 13 pp.

Pettingell-Andrews Co., Boston, Mass. June 1910—Juice, a magazine published, giving information about the electrical industry. 16 pp.

Providence Engineering Works, Providence, R. I. Bull. S.-75. " Rice and Sargent " Corliss engine. 55 pp.

Western Electric Co., Hawthorne, N. Y. Bull. No. 1110—Telephone and signaling apparatus for mines; mine plan and wiring diagram. 7 pp.

——Bull. No. 5210—" Hawthorne " alternators. 15 pp.

——Bull. No. 5533—Series incandescent lighting system with " Sunbeam Mazda " lamp. 15 pp.

United Engineering Society.

Poor's Manual of Industrials, 1910. New York, Poor's Railroad Manual Co., 1910. (Purchase.)

OFFICERS AND BOARD OF DIRECTORS, 1910-1911.

PRESIDENT.

(Term expires July 31, 1911.)

DUGALD C. JACKSON.

JUNIOR PAST-PRESIDENTS.

LOUIS A. FERGUSON.

LEWIS B. STILLWELL

VICE-PRESIDENTS.

(Term expires July 31, 1911.)

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(Term expires July 31, 1911.)

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(Term expires July 31, 1912.)

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(Term expires July 31, 1913.)

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GEORGE A. HAMILTON.

(Term expires July 31, 1911.)

SECRETARY.

RALPH W. POPE.

NOTE:—The Institute Constitution provides that the above named twenty-three officers shall constitute the Board of Directors.

PAST-PRESIDENTS.—1884-1909.

*NORVIN GREEN, 1884-5-6.
*FRANKLIN L. POPE, 1886-7.
T. COMMERFORD MARTIN, 1887-8.
EDWARD WESTON, 1888-9.
ELIHU THOMSON, 1889-90.
*WILLIAM A. ANTHONY, 1890-91.
ALEXANDER GRAHAM BELL, 1891-2.
FRANK J. SPRAGUE, 1892-3.
EDWIN J. HOUSTON, 1893-4-5.
LOUIS DUNCAN, 1895-6-7.
FRANCIS B. CROCKER, 1897-8.
A. E. KENNELLY, 1898-1900.
CARL HERING, 1900-1.
CHARLES P. STEINMETZ, 1901-2.
CHARLES F. SCOTT, 1902-3.
BION J. ARNOLD, 1903-4.
JOHN W. LIEB, JR., 1904-5.
SCHUYLER S. WHEELER, 1905-6.
SAMUEL SHELDON, 1906-7.
HENRY GORDON STOTT, 1907-8.
LOUIS A. FERGUSON, 1908-09.
LEWIS BUCKLEY STILLWELL 1909-10

*Deceased.

ASSISTANT SECRETARY.

FREDERICK L. HUTCHINSON,
33 West 39th Street, New York.

GENERAL COUNSEL.

PARKER and AARON,
52 Broadway, New York

LOCAL HONORARY SECRETARIES.

JAMES S. FITZMAURICE,
210 George St., Sydney, N. S. W.
H. P. PARSHALL,
Salisbury House, London Wall, E. C., London.
WILLIAM B. HALE,
Cadena 10, City of Mexico.
W. G. T. GOODMAN,
Adelaide, South Australia.
ROBERT J. SCOTT,
Christ Church, New Zealand
HENRY GRAFTIO, St. Petersburg, Russia.
L. A. HERDT, McGill University, Montreal, Que

LIST OF SECTIONS.

Name and when Organized	Chairman.	Secretary.
Atlanta...........Jan. 19, '04	H. P. Wood.	M. E. Bonyun, G. E. Co., Atlanta, Ga.
Baltimore.........Dec. 16, '04	J. B. Whitehead.	L. M. Potts, 107 East Lombard St., Baltimore, Md.
Boston............Feb. 13, '03	J. F. Vaughan.	Harry M. Hope, 147 Milk Street, Boston, Mass.
Chicago..................1893	J. G. Wray.	E. N. Lake, 181 La Salle St., Chicago, Ill.
Cleveland.........Sept. 27, '07	A. M. Allen.	Howard Dingle, 912 N. E. Building, Cleveland, Ohio.
Fort Wayne.......Aug. 14, '08	E. A. Wagner.	J. V. Hunter, Fort Wayne Electric Works, Ft. Wayne, Ind.
Ithaca............Oct. 15, '02	E. L. Nichols.	B. C. Dennison, Cornell University Ithaca, N. Y.
Los Angeles.......May 19, '08	J. A. Lighthipe.	J. E. MacDonald, 444 P. E. Bldg., Los Angeles, Cal.
Madison..........Jan. 8, '09	M. H. Collbohm	H. B. Sanford, Univ. of Wisconsin, Madison, Wis.
Mexico...........Dec. 13, '07	E. Leonarz.	Gustavo Lobo, Cadena Street, No. 2, Mexico, Mex.
Milwaukee........Feb. 11, '10	W. H. Powell.	L. L. Tatum, Cutler-Hammer Mfg. Co., Milwaukee, Wis.
Minnesota.........Apr. 7, '02	J. C. Vincent	J. H. Schumacher, 2716 University Ave., Minneapolis, Minn
Norfolk...........Mar. 13, '08		R. R. Grant, P. O. Box 254, Norfolk, Va
Philadelphia.......Feb. 18, '03	C. I. Young.	H. F. Sanville 608 Empire Building, Philadelphia, Pa.
Pittsburg..........Oct. 13, '02	C. B. Auel.	E. B. Tuttle, C. D. & P. Tel. Co., Pittsburgh, Pa.
Pittsfield..........Mar. 25, '04	S. H. Blake.	W. C. Smith, General Electric Company, Pittsfield, Mass.
Portland, Ore......May 18, '09	L. B. Cramer,	F. D. Weber, 559 Sherlock Building, Portland, Ore.
San Francisco.....Dec. 23, '04	George R. Murphy	S. J. Lisberger, 445 Sutter St., San Francisco, Cal.
Schenectady.......Jan. 26, '03	M. O. Troy.	R. H. Carlton, Gen. Elec. Co., Schenectady, N. Y.
Seattle............Jan. 19, '04	A. A. Miller.	W. S. Hoskins, 1428 21st Avenue, Seattle, Wash.
St. Louis..........Jan. 14, '03	George W. Lamke.	F. W. L. Peebles, Chemical Building, St. Louis, Mo.
Toledo............June 3, '07	M. W. Hansen.	Geo. E. Kirk, 1649 The Nicholas, Toledo, O.
Toronto...........Sept. 30, '03	H. W. Price.	W. H. Eisenbeis, 1207 Traders' Bank Bldg., Toronto, Can
Urbana...........Nov. 25, '02	Charles T. Knipp.	J. M. Bryant, 610 West Oregon St., Urbana, Ill.
Washington, D. C...Apr. 9, '03	Earl Wheeler.	H. B. Stabler, 1214 I St., Washington, D. C.

Total, 25.

LIST OF BRANCHES.

Name and when Organized.		Chairman.	Secretary.
Agricultural and Mechanical College of Texas....Nov.	12, '09	V. H. Braunig.	R. T. Shiels, A. and M. Col. of Tex., College Sta., Texas
Arkansas, Univ. of...Mar.	25, '04	W. B. Stelzner.	F. S. White, 523 Willow St., Fayetteville, Ark.
Armour Institute....Feb.	26, '04	W. G. Tellin.	E. H. Freeman, Armour Inst. Tech., Chicago, Ill.
Bucknell University..May	17, '10	C. N. Brubaker.	A. J. Huston, Bucknell University, Lewisburg, Pa.
Case School, Cleveland....Jan.	8, '09	S. G. Boyd.	Don C. Orwig, 2171 Cornell Road, Cleveland, Ohio.
Cincinnati, Univ. of..Apr.	10, '08	C. R. Wylie.	Ralph B. Kersay, 315 Jackson St., Carthage, Ohio
Colorado State Agricultural College......Feb.	11, '10	Alfred Johnson.	D. E. Byerley, 229 N. Loomis Street, Fort Collins, Colo.
Colorado, Univ. of...Dec.	16, '04	Ernest Prince.	R. B. Finley, University of Colorado, Boulder, Colo.
Iowa State College...Apr.	15, '03	Frank K. Shuff.	
Iowa, Univ. of.......May	18, '09	H. E. Scheark.	A. H. Ford, University of Iowa, Iowa City, Ia.
Kansas State Agr. Col. Jan.	10, '08	R. E. Talley.	B. F. Eyer, 513 Fremont St., Manhattan, Kansas.
Kansas, Univ. of.....Mar.	18, '08	V. S. Foster.	R. L. Ponsler, Univ. of Kansas, Lawrence, Kans.
Lehigh University....Oct.	15, '02	H. H. Fithian.	Jacob Stair, Jr., Lehigh University, Bethlehem, Pa.
Lewis Institute.......Nov.	8, '07	J. C. Johnson.	A. H. Fensholt, Lewis Institute, Chicago, Ill.
Maine, Univ. of......Dec.	26, '06	A. T. Childs.	J. P. King, University of Maine, Orono, Maine.
Michigan, Univ. of...Mar.	25, '04	E. B. McKinney.	Gerald J. Wagner, 454 S. First St., Ann Arbor, Mich.
Missouri, Univ. of....Jan.	10, '03	H. B. Shaw.	A. E. Flowers, Univ. of Missouri, Columbia, Mo.
Montana State Col...May	21, '07	C. C. Kennedy.	J. A. Thaler, Montana State College, Bozeman, Mont
Nebraska, Univ. of...Apr.	10, '08	Geo. H. Morse.	V. L. Hollister, Station A, Lincoln, Nebraska.
New Hampshire Col..Feb.	19, '09	C. E. Hewitt.	L. W. Bennett, New Hampshire College, Durham, N. H.
North Carolina Col. of Agr. and Mech. Arts....Feb.	11 '10	Wm. H. Browne, Jr.	E. B. Moore, N.C.C.A. and M.A., West Raleigh, N.C.
Ohio State Univ......Dec.	20, '02	H. W. Leinbach.	F. L. Snyder, 128 E. Blake Ave., Columbus, Ohio.
Oregon State Agr. Col. Mar.	24, '08	E. R. Shepard.	W. Weniger, Ore. State Agricul. College, Corvallis, Ore.
Penn. State College...Dec.	20, '02	C. M. Wheeler.	J. M. Spangler, Penn. State College, State College, Pa.
Purdue Univ.........Jan.	26, '03	C. F. Harding.	H. T. Plumb, Purdue University, Lafayette, Ind
Rensselaer Polytechnic Institute.......Nov.	12, '09	E. D. N. Schulte.	W. J. Williams, Rensselaer Poly. Institute, Troy, N Y.
Stanford Univ.......Dec.	13, '07	T. W. Snell.	J. H. Leeds, Stanford University, California
Syracuse Univ.......Feb.	24, '05	W. P. Graham.	A. R. Acheson, Syracuse University, Syracuse, N. Y.
Texas, Univ. of......Feb.	14, '08	B. E. Kenyon.	J. A. Correll, University of Texas, Austin, Tex.
Wash., State Col. of..Dec.	13, '07		M. K. Akers, State Col. of Wash., Pullman, Wash.
Washington Univ....Feb.	26, '04	Geo. W. Pieksen.	
Worcester Poly. Inst..Mar.	25, '04	W. C. Greenough.	H. E. Hartwell, Worcester Poly. Inst., Worcester, Mass.

Total, 31

PROCEEDINGS

OF THE

American Institute

OF

Electrical Engineers.

Published monthly at 33 W 39th St., New York, under the supervision of

THE EDITING COMMITTEE

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Vol. XXIX **September, 1910** No. 9

Directors' Meeting August 12, 1910

The first meeting of the Institute Board of Directors under the new administration was held at 33 West 39th Street. New York City, on Friday, August 12, 1910. The directors present were: President Dugald C. Jackson, Boston, Mass.; Vice-President Percy H. Thomas, New York; Managers, A. W. Berresford, Milwaukee, Wis., H. E. Clifford, Cambridge, Mass., W. G. Carlton, New York, H. H. Norris, Ithaca, N. Y., W. S. Rugg, New York, David B. Rushmore, Schenectady, N. Y., Severn D. Sprong, New York; Treasurer George A. Hamilton, Elizabeth, N. J.; Secretary Ralph W. Pope, New York.

Eighty-nine candidates for admission to membership in the Institute as Associates were elected.

Thirteen Students were declared enrolled.

Eight Associates were transferred to the grade of Member, as follows:

Jens Ludwig Hansen, The Electricity Company, Ltd., Bangkok, Siam.

Milton Ulmer, General Attorney and Engineer, Schondube & Neugebauer, Mexico City, Mexico.

Brent Wiley, Commercial Engineer, Westinghouse Electric and Manufacturing Company, Pittsburgh, Pa.

William Arthur Thomas, Commercial Engineer in sales department, Westinghouse Electric and Manufacturing Company, Pittsburgh, Pa.

Harold Pender, Professor of Theoretical and Applied Electricity Massachusetts Institute of Technology, Boston, Mass.

V. Alfred Fynn, Consulting Engineer, St Louis, Mo.

Robert Payne Fairbanks, in charge of preparation for research work of Telluride Institute at Cornell University, Ithaca, N. Y.

Jakob Emil Noeggarath, Consulting Engineer, New York.

President Jackson announced his appointments of the standing and special committees for the current administrative year ending July 31, 1911. A list of these committees is printed elsewhere in this issue. By authority of the Board of Directors the President added auxiliary members to a number of the standing and special committees. Two new technical committees were appointed; namely, electrochemical committee, and power station committee. These committees were appointed for the purpose of promoting and coordinating Institute activity in their respective fields. The former was authorized by the Board at the instance of Past-President Stillwell on November 12, 1909, who suspended action on the appointment, and the latter was authorized on the recommendation of President Jackson at the meeting of August 12, 1910.

Canal Zone Meeting American Institute of Mining Engineers

The American Institute of Mining Engineers will hold a meeting in the Canal Zone, Panama, in November, 1910. The steamer *Prinz August Wilhelm* of the Hamburg-American Steamship Company, accommodating about 150 passengers, has been engaged for the trip, and will sail with the party from New York on October 21, returning to New York about November 15, 1910. The cost of the round trip, including berth in stateroom, meals on steamer, railroad transportation, meals and accommodations at the Hotel Tivoli in the Canal Zone, will be $200 for each member or guest. This rate can be obtained only by those who secure accommodations prior to September 15, after which date an additional charge of $50 per capita must be made. The dates of payments necessary to secure a reservation are $100 not later than September 15, and $100 on October 1. Stops will be made at Havana, Kingston, Colon, Port Limon, and a call at Fortune Island. About 136 persons have made reservations, but there is still room for more in the party, and the members of the American Institute of Electrical Engineers are cordially invited to participate in this meeting. As the first week in November belongs to the rainy season, and it may rain hard for brief periods during the visit, members who attend should be provided with water-proof coats and high water-proof foot covering suitable for tramping in mud and water. Thus provided they need not fear the terrors of the rainy season, and they will have an opportunity to see how American engineers deal with such unfavorable climatic conditions. This trip will be of unusual interest to engineers owing to the rapid progress of the work on the canal. The details of the visits and excursions while on the Isthmus and the time and place of the technical sessions of the Institute have not yet been completed. The management of the trip is in the hands of Dr. Joseph Struthers, Assistant Secretary of the American Institute of Mining Engineers, 29 West 39th Street, New York City, to whom remittances and communications should be addressed.

Section Meeting

The Chicago Section held a joint meeting with the Electrical Section of the Western Society of Engineers on July 8, 1910. Mr. W. A. Blonck gave an illustrated lecture upon the subject of recent European progress in dirigible balloons. Those who discussed the paper were: Messrs. W. E. Symons, W. H. Finley, George M. Mayer, George B. Foster, A. Bement, J. R. Cravens, J. E. Johnson, and E. N. Lake. Sixty-five members of both societies attended the meeting.

Second National Conservation Congress, St. Paul Minn., September 5–9, 1910

The Second National Conservation Congress will be held in St. Paul, Minn., September 5 to 9, inclusive, 1910. The objects of this National Conservation Congress will be:

1. To provide for discussion of the resources of the United States as the foundation for the prosperity of the people.
2. To furnish definite information concerning the resources and their development, use and preservation.
3. To afford an agency through which the people of the country may frame policies and principles affecting the conservation and utilization of their resources to be put into effect by their representatives in State and Federal Governments.

Civic and national organizations throughout the country have been invited to send delegates to the Congress. The American Institute of Electrical Engineers will be represented by the following five delegates appointed by President Jackson: William B. Jackson, chairman, Chicago, Ill.; Morgan Brooks, Urbana, Ill.; E. P. Burch, Minneapolis, Minn.; A. W. Leonard,

Minneapolis, Minn.; Ralph W. Pope, New York. In view of the interest manifested by foreign governments in the conservation movement in the United States, and the proposed World Conservation Congress at The Hague, an invitation to send representatives to the Congress has been extended, through their diplomatic representatives at Washington, to each of the forty-five nations which participated in the International Peace Conference.

Reunion Amicale of the International Electrotechnical Commission

An unofficial reunion of the International Electrotechnical Commission was held at Brussels, August 8—11, 1910. Twelve countries were represented, and 47 delegates were in attendance. Dr. A. E. Kennelly and Mr. C. F. Scott represented the United States and the A.I.E.E. The meeting this year was in preparation for the plenary convention which is to be held next year, so that the proposals offered at this time are not final and ample time for their further discussion is afforded.

Four subjects were discussed by the reunion, namely, international symbols, standard rating of generators and motors, standardization of direction of vector rotation, and nomenclature. The recommendations made on these subjects must be ratified at the next plenary convention.

Associates Elected August 12, 1910

ALLAN, SIDNEY FRANCIS, Electric Construction Engineer, Oklahoma Railway Co., Oklahoma City, Okla.

BACON, FRANK ROGERS, President, Cutler-Hammer Manufacturing Co., Milwaukee, Wis.

BARLEY, ARTHUR THOMAS, Draftsman, with W. E. Wood, 1713 Ford Bldg.; res., 850 14th Ave., Detroit, Mich.

BARNES, ALFRED HENRY, Assistant in Physics, Ohio State University; res., 325 West 10th Ave., Columbus, Ohio.

BARRON, AMOS NOYES, National Carbon Co.; res., 1912 East 71st St., Cleveland, Ohio.

BLOCH, ALFRED, 4 Rue Meyerbeer, Paris, France.

BLOCKSIDGE, GARNET, Sales Department, Westinghouse Electric & Mfg. Co., Pittsburg, Pa.

BODINE, HENRY KEITH, Draughtsman, Camden Coke Co., Camden; res., Stratford, N. J.

BROWN, ARTHUR JAMES, Chief Draftsman, Allis Chalmers Co.; res., 3307 McKinley Blvd., Milwaukee, Wis.

BROWN, HARRY FARNSWORTH, Draftsman, Electrical Dept., N. Y., N. H. & H. R.R., New Haven, Conn.

BROWNING, HOWARD LEON, Sales Department, Fort Wayne Electric Works, Fort Wayne, Ind.

CAMPBELL, ARTHUR CLAYTON, Chief Engineer, Columbia Power & Light Co., Walla Walla, Wash.

CARBUTT, ROBERT FOSTER, Engineer, Henry L. Doherty & Co., 60 Wall St., New York City.

CHATTERTON, RALPH RAY, Chief Electrician, Iowa State College, Ames, Iowa.

CLIZBE, RAY ELLIS, Expert Electrician, Pullman Car Co., Pullman, Illinois.

COOLIDGE, WILLIAM DAVID, Assistant Director of Research Laboratory, General Electric Co., Schenectady, N. Y.

COUSINS, R. W., Electrical Engineer, Indiana Steel Co., Gary, Indiana.

CREAGH, HAROLD, Assistant Works Manager, Lancashire & Forkshire Railway, Newton Heath, Manchester, England.

CROOKES, SAMUEL IRWIN, Head of Electrical Engineering Department, The Technical College, Auckland, New Zealand.

CROUSE, RALPH CLINTON, Salesman, Illinois Electric Co.; res., 4026 Grand Boulevard, Chicago, Ill.

DEMPSEY, GEORGE THOMAS, Assistant Engineer, American Gas Co., 224 So. 3rd St., Philadelphia, Pa.

DORN, WILLIAM GEORGE, Master Electrician, Automatic Electric Co., Morgan and Van Buren Sts., Chicago, Ill.

DOWNIE, JOHN WILLIAMS, Electrician, Christchurch City Council, Christchurch, N. Z.

DYER, LESLIE L., Operator in Charge, Pacific Light & Power Co., Redondo Beach, California.

ECKART, NELSON ANDREW, Resident Engineer, Snow Mountain Water & Power Co., Potter Valley, Cal.

EHRLICH, HOWARD, Associate Editor, Electrical Review & Western Electrician; res., 350 East 53rd St., Chicago, Ill.

ESTBERG, HOWARD CLAES, Manager, Greeley Gas and Fuel Co., Greeley, Colo.

FERRO, THOMAS EDWARD, Assistant, Electrical Branch, P. W. D. Fort, Bombay, India.

FLEMING, SAMUEL WILSON, JR., Power Engineering Department, Newburgh Light, Heat and Power Co., Newburgh, N. Y.

FOX, ALVIN, Electrical Engineer, Commonwealth Edison Co., Fisk Street Station; res., 1249 La Salle Ave., Chicago, Ill.

FRANCIS, HAROLD ROBERT, Remy Electric Co.; res., 471 Woodward Ave., Detroit, Mich.

GRISWOLD, AUGUSTUS HAROLD, Plant Engineer, Pacific Telephone & Telegraph Co., 140 New Montgomery St., San Francisco, Cal.

HALL, CHESTER IRVING, Electrical Engineer, Minerallac Electric Co.; res., 5353 Kenmore Ave., Chicago, Ill.

HANSEN, KARL H., Assistant Chief Engineer, Union Electric Light & Power Co., 415 North 10th St., St. Louis, Mo.

HART, PHILIP EWING, Mechanical & Constructing Electrical Engineer, 91 Mackay Street, Montreal, Canada.

HATFIELD, KENNETH GEORGE STACY, Mechanical and Electrical Engineer, British Westinghouse Electrical & Mfg. Co., Ltd., Old Trafford, Manchester, England.

HEIDTMANN, ALBERT WILLIAM, Engineering Dept., New York Central & Hudson River Railroad Co., 335 Madison Ave., New York City.

HILL, LYLE STEEN, Director of Roentgen Laboratory, University Hospital; res., 1000 East Ann St., Ann Arbor, Mich.

HUDSON, RALPH GORTON, Instructor of Electrical Engineering, Massachusetts Institute of Technology, Boston, Mass.

HUGHES, EDWARD, Engineer in Charge, La Compania de Energia Electrica de Barranquilla, Barranquilla, Columbia, S. A.

JEFFERY, JOHN JAMES, Electrical Engineer, Smith, Kerry and Chace, Confederation Life Building, Toronto, Ont.

JONES, HENRY HARRISON, Manager, San Diego Consolidated Gas and Electric Co., San Diego, Cal.

JONES, NELSON Engineer, National Electrical & Engineering Co., Ltd.; res., 7 Ferguson St., Dunedin, N. Z.

JOSEPH, GEORGE, Assistant, Central Power Station, Bombay Electric Supply & Tramway Co., Mazagon, Bombay, India.

KELSALL, GEORGE AVERY, Instructor in Electrical Engineering, Michigan Agricultural College, East Lansing, Mich.

KEMP, JOHN THEODORE, Electrical Engineer, J. T. Kemp & Co., 409 S. Main St., Findlay, Ohio.

KLIPPELT, JAMES ROBINSON, Plant Supervisor, Central District & Printing Tel. Co., Uniontown, Pa.

LAUHREN, NILS LAURITZ, Construction Engineer, Aktiebolaget Stockholmstelefon, Stockholm, Sweden.

LEIGH, ALBERT, Foreman, Hydro-Electric Substation, Pacific Gas & Electric Co., Mission, San Jose, Cal.

LUCK, FREDERICK JOHN WHITMORE, Electrical Engineer, Walter Brothers & Co., 65 General Camara, Rio de Janeiro, Brazil.

Manzer, Frank Eugene, Construction Foreman, Dept. of Electrical Engineering, Southern Pacific Railway Co., San Francisco, Cal.

Matheson, William Barclay, Salesman, Pacific States Electric Co., 326 South Los Angeles St., Los Angeles, Cal.

Maujer, Robert Irving, Cutler-Hammer Mfg. Co., Schofield Bldg., Cleveland, Ohio.

Maynard, Cloyd Tabor, Electrical Engineer, Vermont Marble Co., Proctor, Vt.

McNiece, Thomas Meily, Electrical Engineer, National Carbon Company; res., 1464 W. 117th St., Cleveland, O.

Miller, Edgar Bruno, Superintendent Power Plant Construction, Panhandle Lumber Co., Ione, Washington.

Moffitt, Le Roy, Engineer's Inspector, Southern Bell Telephone & Telegraph Co., 78 S. Pryor Street, Atlanta, Ga.

Moran, Harry P., System Operator, Central Colorado Power Co., Denver, Colo.

Motter, William Nelson, Engineer, Allis-Chalmers Co.; res., 99 32nd St., Milwaukee, Wis.

Moultrop, Irving E., Mechanical Engineer, Edison Electric Illuminating Co. of Boston, 39 Boylston St., Boston, Mass.

Mullegren, Arthur Leonard, Superintendent, Poteau Light & Ice Co., Poteau, Oklahoma.

Newnham, Eugene, Engineer, Robbins & Meyers Co.; res., 835 N. Limestone St., Springfield, Ohio.

Ojeda, Agustin Mariano, Student, Ohio State University; res., 85 16th Ave., Columbus, Ohio.

Parker, Frank Ingram, Electrical Engineer, Cutler-Hammer Clutch Co., Milwakuee, Wis.

Partridge, Gerald William, Chief Engineer, London Electric Supply Corporation; res., 14 Cavendish Road, Regents Park, London, England.

Perry, Ray Herman, In Charge of Telephone Plant, Knoxville Electric Co., Knoxville, Iowa.

Philips, Harry E., Superintendent Generating Station, Winnipeg, Elec. Railway Co., Pinawa, Manitoba.

Piekson, George William, Student, Washington University, St. Louis, Mo.

Pierce, Frederick Louis, Vice-President and Treasurer, Cutler-Hammer Mfg. Co.; res., 176 Farwell Ave., Milwaukee, Wis.

Prado, Hazael Colatino, Electrical Engineer, Cali, Colombia, S. A.

Reisbach, Gustav B., Chief Draftsman, Cutler-Hammer Mfg. Co.; res., 144 23rd St., Milwaukee, Wis.

Reyes, Cecilio Torres, Superintendent of Schools of Corozal, Department of Education, San Juan; res., Corozal, P. R.

Roop, James Clawson, Instructor in Electrical Engineering, University of Pennsylvania, Philadelphia; res., Upland, Pa.

Schmidt, Albert Richard, A. R. Schmidt Electric Co., 137 Oneida St.; res., 3209 Chestnut St., Milwaukee, Wis.

Shute, Nathan, District Sales Agent, Ohio Brass Co., 1510 Land Title Bldg., Philadelphia, Pa.

Staeffen, Henry George Edward, Electro-Chemist, American Vanadium Co., Bridgeville; res., 620 Sherman Ave., N. S. Pittsburg, Pa.

Stanton, Charles S., Electrical Engineer, Otsego & Herkimer R.R. and Hartwick Power Co., Hartwick, N. Y.

Starkey, William Carleton, Engineer, Ohio Brass Company; res., 14 Helen Avenue, Mansfield, Ohio.

Stotler, Edwin John, Chief Electrician, Texas Portland Cement Co., Cement, Texas.

Voorhees, Wheeler Newman, Construction Foreman, General Electric Co.; res., 595 Tenth St., Brooklyn, N. Y.

Vreeland, Frank Peck, Railway and Traction Engg. Dept. General Electric Co.; res., 618 Chapel St., Shenectady, N. Y.

WACKWITZ, ERNEST FREDERICK, Chief Electrical Engineer, Peerless Motor Car Co., res., 1220 East 111th St., Cleveland, Ohio.

WALDRON, RICHARD, JR., Electrician, Board of Fire Underwriters of the Pacific 318 Security Bldg., Los Angeles, Cal.

WALKER, THOMAS PHILIP, Inspector of Underground Electrical Construction, City of Toronto; res., 99 Gloucester St., Toronto, Ont.

WATSON, THOMAS SIDNEY, Consulting Engineer, 537 Hartford Ave., Milwaukee, Wis.

WOODHULL, FRED HOWARD, Superintendent Electrical Department, Lukens Iron & Steel Co., Coatesville, Pa.

WOODRUFF, LELAND SARGENT, Electrical Engineer, Allis-Chalmers Co.; res., 5031 National Ave., West Allis, Wis.

WORTHAM, EDWIN, Draughtsman, Virginia Railway and Power Company; res., 821 West Main St., Richmond, Va.

YERGER, CHARLES WILLIAM, Electrical Engineer, Cutler-Hammer Mfg. Co., 183 14th St., Milwaukee, Wis.

Applications for Election

Applications have been received by the Secretary from the following candidates for election to membership in the Institute as Associates. These applications will be considered by the Board of Directors at a future meeting. Any Member or Associate objecting to the election of any of these candidates should so inform the Secretary before September 25, 1910.

9651 Boyce, B. K., New York City.
9652 Gunning, J. F., New York City.
9653 Clary, W. H., Round Lake, N. Y.
9654 Timmerman, H. E., Campbellford, Ont.
9655 Brantly, Edgar C., Tuscaloosa, Ala.
9656 Hildenbrand, H., Houston, Texas.
9657 Parsons, W. N., Mexico City, Mex.
9658 Ryan, John J., Chicago, Ill.
9659 Stage, R. C., Elmira, N. Y.
9660 Goodspeed, M. C., Erie, Pa.
9661 Edwards, L., Burrand, V. C.
9662 Easter, R. R., Seattle, Wash.
9663 Smith, Perd O., Ft. Wayne, Ind.
9664 Benjamin, C. L., Milwaukee, Wis.
9665 Collins, P. E., Ossining, N. Y.
9666 Jones, E. J., Ocala, Fla.
9667 Nisar, A. R., Chicago, Ill.
9668 Morgan, J. T., Charleston, W. Va.
9669 Schreiber, K. E., Kansas City, Mo.
9670 Van Meter, R. H., Laconia, N. H.
9671 Waldorf, F., Chicago, Ill.
9672 Kirchgasser, G. J., Milwaukee, Wis.
9673 Ritter, H. K., Baden, Switzerland.
9674 Tobias, D. F., New York City.
9675 McGinty, James A., So. Atlanta, Ga.
9676 Parkinson, F. W., Minneapolis, Minn.

Total 26.

Students Enrolled August 12, 1910

3777 Powell, J. W., Oregon Agr. College.
3778 Weimer, G. O., Ohio State Univ.
3779 Swift, F. H., University of Oregon.
3780 Haynes, H. A., Univ. of Pittsburg.
3781 Clingman, P., Univ. of Cincinnati.
3782 Neill, J. K., Univ. of Oregon.
3783 Boyles, R. A., Univ. of Michigan.
3784 Morris, G. S., University of Kansas
3786 Dieterich, F. W., Univ. of Wis.
3787 Fowler, F. W., Kansas State Agr. Col.
3788 Phelps, Ray R., Univ. of Minn.
3789 Sotto, F., Highland Park College.
3790 Walker, F. M., Univ. of Michigan.

Total 13.

Personal

MR. J. B. CAMERON has been appointed assistant engineer with the Baltimore and Ohio Railroad Company at Somerset, Pa.

MR. C. F. BALDWIN has opened an office in Ironton, Ohio, where he will conduct a general consulting engineering business.

MR. ALFRED W. BEUTTELL announces his removal to 2 Voss Court, Streatham Common South, London, S. W., England.

MR. LEIGH SHELTON KEITH, managing engineer for McMeen and Miller

Chicago, Ill., was married on July 25, 1910, to Miss Jeanette Munroe.

MR. JAMES M. WILEY, electrical engineer for the Holly Sugar Company, Holly, Colo., has been transferred to the company's plant at Swink, Colo.

MR. J. H. HALLBERG, consulting engineer, has removed from 45 Broadway and 30 Greenwich Avenue to 36 East 23rd Street, New York City.

MR. MORGAN T. COAKLEY having completed the Westinghouse electrical engineering course is visiting at his home in Buffalo prior to touring Colorado.

MR. G. H. PALMER has resigned from the Telluride Power Company to accept the position of operating superintendent for the Arizona Power Company, of Prescott, Arizona.

MR. G. C. THORNTON, of Thornton Brothers, engineers, of Birmingham, Ala., has resigned to take a position as engineer for the Mine and Smelter Supply Company, El Paso, Texas.

MR. C. C. CONDON, of the Condon Construction Company of Chicago, Ill., is at present engaged upon the rebuilding of the plant of the Paxton Electric Company at Paxton, Ill.

MR. M. O. HAMBLIN, formerly with the Commonwealth Power Company, Augusta, Michigan, has been appointed electrical engineer with the Michigan Power Company, Lansing, Michigan.

MR. WILLIAM ELSDON-DEW, formerly engineer with Witwatersrand Deep, Limited, Knights, Transvaal, has joined the engineering staff of H. Eckstein and Company, Johannesburg, Transvaal.

MR. J. H. FORD, recently district engineer of the Fourth District, Philippine Islands, has accepted the position of chief engineer for Irwin and Leighton, Franklin Building, Philadelphia, Pa.

MR. A. R. THOMPSON, who for eight years was in the engineering department of the New York Edison Company, is now connected with the Pacific Gas and Electric Company, at San Francisco Cal.

MR. H. S. WILLIAMS has resigned his position as electrical engineer of the Mohawk Valley Railway Company to become chief engineer of the Peter Smith Heating Company, of Detroit, Mich.

MR. PHILANDER BETTS has been appointed chief engineer of the Board of Public Utility Commissioners of New Jersey. Mr. Betts has been practising as consulting engineer and expert in Washington for several years.

MR. ALDIS E. HIBNER has resigned from the engineering department of the Rochester Railway and Light Company to become assistant power engineer for the Toronto Electric Light Company, Toronto, Ont.

MR. T. R. MILLAR, until recently with the Ontario Power Company, Niagara Falls, N. Y., has accepted a position with the Shawinigan Water and Power Company, Shawinigan Falls, P. Q., Canada.

MR. JOSEPH H. SCHAEFER, formerly in the plant department of the Chicago Telephone Company, is now in the telegraph department of the New York Central and Hudson River Railroad Company at Syracuse, N. Y.

MR. B. H. CHATTO has resigned from the transformer department of the General Electric Company at Lynn, Mass., to become electrical engineer for the Dilg Manufacturing and Trading Company, New York City.

MR. E. W. SANDERSON, inspector in the metropolitan district of the Western Electric Company, New York City, was recently transferred to Greenwich, Conn., as inspector of the installation of a new telephone central office.

MR. A. B. SMALLHOUSE, consulting electrical and mechanical engineer, formerly of Salt Lake City, Utah, has been appointed chief electrical engineer of electrical equipment for the Carney Coal Company, Carneyville, Wyoming.

MR. S. N. CLARKSON, of the Westinghouse Electric and Manufacturing Company, has accepted a position with the Union Electric Light and Power Company of St. Louis, Mo., as commercial engineer in their new business department.

MR. CARLOS M. SEIDEL, electrical engineer, representative in Havana, Cuba, of the Watson-Stillman Company of New York, and the Crocker-Wheeler Company, Ampere, N. J., has changed his post office address to Apartado 721, Havana, Cuba.

MR. HANS E. AANONSEN has accepted a position as electrical engineer with Aktieselskabet Tyssefaldene, Christiana, Norway. Mr. Aanonsen was formerly chief draftsman for the Niagara, Lockport and Ontario Power Company at Buffalo, N. Y.

MR. H. L. SAMPSON, formerly with the Board of Supervising Engineers, Chicago Traction, has accepted a position as chief electrical engineer for the South Utah Mines and Smelters Company, and is now located at Newhouse, Utah.

MR. JOHN C. RENNARD has been appointed electrical engineer of the New York City Fire Department. Mr. Rennard is a graduate of West Point Military Academy and of Columbia University and is a member of various professional and social clubs in New York.

MR. ANTONIO GUELL, research fellow in the engineering experiment station of the University of Illinois, having received the degree of electrical engineer from that institution, has entered the employ of the General Electric Company at Lynn, Mass.

MR. RUSSELL YOUNG, formerly with the Vancouver Power Company, is now superintendent of electrical construction of the Fraser Valley branch of the British Columbia Electric Railway Company, with headquarters in the Westminster, B. C., office.

MR. J. G. ROSS, has removed from 150 Nassau Street and is now engaged in the design and construction of electrical and mechanical stage apparatus for the Theatre Stage Construction Company, 116 West 39th Street, New York City.

MR. L. R. POMEROY, who recently resigned the position of assistant to the president of the Safety Car Heating and Lighting Company, has been appointed chief engineer of the railway and industrial division of J. G. White and Company, New York.

MR. R. J. RANDOLPH, JR., formerly with the Crocker-Wheeler Company at Ampere, N J., has resigned, and is now manager of the engineering department of the Indian Refining Company, with headquarters in the first National Bank Building, Cincinnati, Ohio.

MR. CHARLES D. COLE, formerly with the Chippewa Valley Electric Light, Railway and Power Company, of Eau Claire, Wis., and the Railway, Gas Light and Power Company of Minnesota, has resigned to enter the electrical department of the Kankakee Electric Light Company, Kankakee, Ill.

Mr. Alfred E. Braddell, for the past two years in the Chicago office of the Sprague Electric Company, has been transferred to the company's general office, 527 West 34th Street, New York City. Mr. Braddell entered the employ of the Sprague Electric Company in the Philadelphia office, in 1905.

Professor George W. Patterson, of the electrical engineering department, University of Michigan, Ann Arbor, Mich., is now in Europe on a year's leave of absence. Professor Patterson will visit Great Britain, France and Germany, and the technical schools and electric railway plants of importance in those countries.

Mr. Charles E. Bonine has opened a consulting engineering office in the Harrison Building, Philadelphia, Pa. Mr. Bonine was previously president and general manager of the Rossmassler-Bonine Electric Company, but his growing engineering practice made it necessary for him to devote more time to his private consultation work.

Mr. Horatio A. Foster, who is associated with Mr. Bion J. Arnold, of Chicago, on appraisal work, is now in Los Angeles going over the properties of the Southern California Edison Company and others. These properties are very widely scattered, from the Kern River power station, about 120 miles north of Los Angeles, to Redlands, 70 miles east, and to Santa Ana, about 35 miles to the south.

Mr. Charles W. Jones, formerly assistant engineer in charge of field engineering and construction work on the New York division of the New York, New Haven and Hartford Railroad Company, has been appointed superintendent of construction for the Stone and Webster Engineering Corporation, Boston, Mass. Mr. Jones is at present engaged upon the construction of water front improvements at the West Jackson Street power plant of the Tampa Electric Company, Tampa, Fla.

Obituary

Albert Spies, engineer, author and editor, died suddenly at his home, 40 Glenwood Ave., Jersey City, N. J., on August 16, 1910. At the time of his death Mr. Spies was proprietor and editor of the newly established Foundry News. Mr. Spies was born in New York, July 20, 1862. In 1881 he graduated from Stevens Institute and was in engineering practice and technical journalism until 1893, when he became editor of *Cassier's Magazine*. Until the death of Louis Cassier and the subsequent sale in 1906 of *Cassier's Magazine* and the *Electrical Age*, Mr. Spies was vice-president, treasurer and managing director of the Cassier Magazine Company and vice-president of the Electrical Age Company. In February 1907 he assumed the editorial conduct of the *Electrical Record*, continuing until February of this year, when he resigned to bring out his own paper, *Foundry News*. In 1895 Mr. Spies was married to Miss Gretchen A. Weisker, who, with a son, survives him.

The personality of Mr. Spies was marked by strong characteristics; his kindliness and courtesy, even under trying conditions, were unfailing; he possessed a great capacity for work and did it thoroughly, the best evidence of this perhaps being his editorial conduct of both *Cassier's Magazine* and the *Electrical Age* for several months unaided; his facility of expression and simple diction made him worthy of Macaulay's saying of Sir Francis Bacon that " he could pack thought close and render it portable." In his letters especially Mr. Spies seemed to impart some of his own personal charm—a letter to a friend was a thing to be treasured, while one soliciting an article had a persuasive power almost irresistable. With those whose coöperation he sought in making engineering literature, he had the reputation of doing and saying the right thing at the

right time and in the right way. In the writer's opinion he was preeminent in the particular field in which he labored longest—that of presenting information to engineers in an attractive form.

His quiet unconscious influence on those with whom he was associated will not soon pass away—his gentleness, his integrity will not soon be forgotten. To those who knew him best his untimely passing is a cause for genuine grief; to the profession it is a loss irreparable.

Mr. Spies was an Associate of the American Institute of Electrical Engineers, having been elected on October 28, 1904, and during recent years devoted much time and energy to the work of the Institute.

ALEXANDER HENDERSON died on Thursday, August 11, 1910, at his home, "The Anchorage", West Moreland Depot, New Hampshire, after a long illness. Mr. Henderson was born in Edinburg, Scotland, on December 21, 1859. When a youth he left school to enter upon a seafaring life, obtaining a berth on one of the vessels in which his father was interested. After a number of years before the mast he located in 1879 in the United States. In 1880 he entered the employ of the Brush Electric Illuminating Company. Later he became associated with the Weston Electric Light Company and The Toledo Brush Electric Light and Power Company, being engaged on construction work and as superintendent of local stations. From 1885 to 1890 he was with the Brush Electric Company of Cleveland, Ohio, as superintendent and constructing engineer. For the next three years he was chief inspector for the Manhattan Electric Light Company, of New York, constructing engineer for the Hunt Engineering Company, of Brooklyn, and general manager of the Brunswick, Maine, Electric Light and Power Company. He subsequently became representative and salesman for the Thomson-Houston Carbon Company and the National Carbon Company, retaining his connection with these concerns until his appointment as chief inspector of the New York Fire Department in the latter part of 1895. On January 1, 1898, under the new charter for New York City this inspection bureau was transferred to the jurisdiction of the Department of Public Buildings, Lighting and Supplies. Mr. Henderson continued as chief inspector until April 1898, when he resigned to accept the position of sales manager with the conduit department of the Sprague Electric Company, of New York, which position he held until 1905. Since that time until his death he was traveling representative of the American Circular Loom Company of Boston. Mr. Henderson was one of the best known men in the electrical profession. During his thirty years of business life he traveled throughout the entire country, his personality winning him friends everywhere. He was a member of many well known clubs and other organizations, and was a mason of high standing. He became an Associate of the Institute on November 29, 1897.

CHARLES TALBOTT, engineering salesman in the Chicago office of the Westinghouse Electric and Manufacturing Company, died in Richmond, Va., on June 19, 1910. Mr. Talbott was born in Richmond on October 1, 1882. His general education was acquired in private schools. In 1901 he entered the employ of the Westinghouse Electric and Manufacturing Company at East Pittsburg, where he spent two years as apprentice. He was then transferred to the Chicago office as engineering salesman. Mr. Talbott became an Associate of the Institute on March 12, 1909.

JOHN DENISON EVARTS DUNCAN, a Life Member of the Institute, who was elected an Associate on March 20, 1895, died at the home of his mother, in Ann Arbor, Michigan, on July 13, 1910. Mr. Duncan was born in Union Falls,

Clinton County, N. Y., in July 1871. When he was eight years of age his parents moved to Ann Arbor, Mich., where he lived until the completion of his technical education. He graduated from high school in 1889 and entered the University of Michigan, from which institution he was graduated in 1893 with the degree of Bachelor of Science in mechanical engineering. He then spent a year in post-graduate work at Cornell University, where he received the Master's Degree in mechanical engineering in 1894. His professional career began the same year with the Terre Haute Street Railway Company, Terre Haute, Ind. Mr. Duncan subsequently held engineering positions in New York City with the Metropolitan Street Railway Company, the Western Electric Company, New York Telephone Company, Westinghouse, Church, Kerr Company, and the Consolidated Railway Electric Lighting and Equipment Company. In February 1901 Mr. Duncan entered the employ of Sanderson and Porter, as managing engineer of their New York office. He was an engineer of exceptional ability and judgment, and in his position with this firm had responsible charge of the design and execution of many important engineering projects. When taken ill Mr. Duncan was returning from a trip of investigation and inspection in the far West where he had gone to examine electrical properties for which his firm is acting as consulting and constructing engineers. Besides being a Life Member of the Institute he was a member of many other societies and organizations. He was married in 1901 to Miss Lena Hill, of Lyons, N. Y., who, with his mother and two brothers, survives him.

Edward Athearn Bessey died at his home in Fort Collins, Colorado, on July 12, 1910. Mr. Bessey was born in Ames, Iowa on June 7, 1875. He graduated from the University of Nebraska in 1896 with the degree of B. Sc., and then took a two-year course in electrical engineering, graduating in 1898 with the degree of B.E.E. After his graduation he entered the service of the Stanley Electric Manufacturing Company, of Pittsfield, Mass., where he worked in various departments until March 1908, when failing health compelled him to go to Colorado. A few months later he entered the employ of the Denver Gas and Electric Company, and later the Central Colorado Power Company. In the fall of 1908 he was appointed instructor in electrical engineering in the Colorado Agricultural College at Fort Collins, which position he held at the time of his death. Mr. Bessey was married on June 19, 1907, to Miss Marion Trotter, at Pittsfield, Mass. He is survived by his widow and a son two years old. He became an Associate of the Institute on July 28, 1903.

Theodore P. Bailey, assistant manager of the General Electric Company, Philadelphia, Pa., died at his home in Mt. Airy, Philadelphia, after an operation for appendicitis, and was buried on Tuesday morning, August 23. Mr. Bailey was born in Covington, Ky., on August 17, 1856. After receiving his education in the public schools at Princeton, Ill., he engaged in newspaper work in that place. In 1879 he became a court reporter at Morris, Ill., which work he continued later in Joliet, Ill. In the meantime he pursued the study of law. In 1881 he was admitted to the bar and shortly afterward removed to Chicago, where he became associated with General A. K. Stiles. General Stiles and Mr. Norman T. Gazette were the original promoters of the Vandepole Electric Company, in which Mr. Bailey was interested, and he thereafter turned his attention to electrical matters. In 1885 he was appointed western representative of the Thomson-Houston Company, and after its merger with the General Electric Company he continued in charge of the street railway business in the Chicago district, later becoming assistant manager of that office. In 1905 he resigned

to enter the railway contracting business as vice-president and general manager of the L. E. Myers Company, Chicago. In the fall of 1908 Mr. Bailey returned to the General Electric Company as assistant manager of the Philadelphia office. For many years Mr. Bailey was one of the most widely known men in street railway circles of the West, and was among the first to project electric light systems in that section of the country. He was elected an Associate of the Institute on April 5, 1902. His widow and one child survive him.

RICHARD JOSEPH NUNN, M.D., after a year of suffering, passed away at his home in Savannah, Ga., on Wednesday morning, June 29, 1910. Dr. Nunn was a native of Ireland, having been born in Wexford on December 13, 1831. In early life he came to America and located in Savannah, Ga., where he began the study of the profession of physician and surgeon. Being a diligent student in everything he undertook he attained a high rank in his profession. He also stood high in the science and philosophy of freemasonry. At the outbreak of the Civil War Dr. Nunn entered the Confederate service as a lieutenant in the Oglethorpe Siege Artillery, which prior to being mustered into service had been organized and equipped through private enterprise. Later he was made captain of the command, a post which he maintained with gallantry for two years. His battery then became Company D, Twenty-second batallion of Georgia Artillery. Failing health compelled his retirement at this time, but he remained on duty at the local hospitals, where he labored with skill and devotion in the cause of the South. At the close of the war Dr. Nunn resumed the practice of his profession and became one of the leading physicians of the state. Early in 1876, his health being greatly impaired, he determined upon a voyage abroad. After a brief absence news reached him that yellow fever had broken out in Savannah. Without stopping to weigh the consequences, he came back as quickly as possible, and during all the trying days of the pestilence he was indefatigable in his efforts to check the ravages of the epidemic.

He subsequently returned to Europe, and a long stay improved his health, but he was never able to undergo the strenuous labors of the first years of his professional life. Dr. Nunn became an Associate of the Institute on July 12, 1887. He was also a member of a large number of other societies both in America and abroad. He never married, and hence leaves no immediate family.

SUKICHI YOSHISAKA, of Kobe, Japan, died on November 6, 1909, after an illness of several months. Mr. Yoshisaka was born on August 30, 1880, in Kobe, Japan. He received his technical education at Purdue University, Lafayette, Indiana, graduating in 1904 with the degree of Bachelor of Science in electrical engineering. After graduation he spent nearly a year in the testing department of the Crocker-Wheeler Company at Ampere, N. J., returning to Japan early in 1905. Mr. Yoshisaka was admitted to membership in the Institute as an Associate on August 25, 1905.

JAMES FRANK PALECEK, commercial engineer of the General Electric Company, Schenectady, N. Y., was drowned in the Mohawk River on June 8, 1910, while canoeing with three friends. It was supposed by his friends that he was a fairly good swimmer, but when the canoe was accidently overturned it was found that he was unable to take care of himself. Every effort was made by his friends to bring him to shore, but without success. Mr. Palecek was born in Cleveland, Ohio, on September 1, 1883. He was a graduate of the Case School of Applied Science, of Cleveland. In July 1906 he entered

the employ of the General Electric Company, where he was for two and a half years in the testing department. He entered the commercial department on November 15, 1908, and at the time of his death he had just returned from a three months' trip through the Middle and South West in the interest of the transformer business of the General Electric Company. Brief funeral services were held in Schenectady on Saturday, June 11, and the remains were shipped to Cleveland. Mr. Palecek was admitted to membership in the Institute as an Associate on March 12, 1909. He is survived by his mother and two sisters.

JAMES HEYWOOD, superintendent of lines and cables of the Philadelphia Rapid Transit Company, died on July 31, 1910, from complications following a minor operation. Mr. Heywood was born in Bolton, England, on November 22, 1875, and came to this country when five years of age. He graduated in 1892 from the Philadelphia Manual Training School, and immediately after engaged in street railway work in Baltimore. In 1893 he entered the engineering department of the People's Traction Company, Philadelphia, Pa., where he had charge of underground cable work. From 1895 to 1902 he continued in the same position for the Union Traction Company, which was later absorbed by the Philadelphia Rapid Transit Company. He was appointed assistant superintendent of lines and cables for the latter company in 1902, and several years afterward advanced to superintendent. Under Mr. Heywood's management the lines and cables department of the Philadelphia Rapid Transit Company was brought to a stage of efficiency which made it a model for other systems. Mr. Heywood was chairman of the committee on power distribution of the American Street and Interurban Railway Engineering Association. He was an Associate of the Institute, having been elected on December 23, 1904.

Library Accessions

The following accessions have been made to the Library of the Institute since the last acknowledgment.

American Street Railway Investments. 1910. New York, McGraw Publishing Co., 1910. (Gift of Publishing Co.)

Automatic Signals for Electric Railways. By C. P. Nachod. (Read before Franklin Institute, April 1910.) n.p. n.d. (Gift of author.)

Congres International de Tramways et de Chemins de fer d Interet Local. Paris, 1900. Responses au Questionnaire. Bruxelles, 1900. (Purchase.)

——Londres, 1902. Comptes-Rendus Detailles. Bruxelles, 1902. (Purchase.)

——Munich, 1908. Comptes-Rendus Detailles. Bruxelles, 1909. (Purchase.)

——Responses aux Questionnaires. Bruxelles, 1908. (Purchase.)

Electrical Trades Directory and Handbook for 1909. London, 1909. (Purchase.)

Forgotten Prime Meridian. By H. E. Ware. (Reprint.) Cambridge, 1910. (Gift of author.)

International Catalogue of Scientific Literature. 7th Annual Issue—chemistry-D. London, 1910. (Gift of Adams Fund.)

Manual of Electrical Undertakings and Directors of Officials. Volume XIII, 1909. London, 1909. (Purchase.)

National Conference on Standard Electrical Rules. Minutes of First Meeting 1896. New York, 1896. (Purchase.)

——Pamphlet containing extracts from the rules in force in 1896 in the United States by various organizations. n.p. n.d. (Purchase.)

National Electric Light Association. Papers, Reports and Discussions. 32d Convention. 1909. Vols. 1-3. New York, 1909. (Exchange.)

——Index to Conventions 1-32, 1885-1909. New York, 1909. (Exchange.)

Osterreichischen Ingenieur-und Architekten-Vereines. XXXIX. Verzeichnis der Mitglieder. 1910. Wien 1910. (Exchange.)

A Pathfinder Discovery, Invention and Industry. By E. G. Acheson. New York, The Press Scrap Book, 1910. (Gift of author.)

Su la Radiazione di Un'Antenna Inclinata. Nota Antonio Garbasso. Roma, 1910. (Donor unknown.)

Travaux du Laboratoire Central d' Electricité. Tome I (1884–1905.) Paris, 1910. (Gift of Société Internationale des Electriciens.)

University of Minnesota. College of Engineering and the Mechanic Arts. Bulletin. Vol. 13, No. 11. Minneapolis, 1910. (Gift of University of Minnesota.)

University of Virginia. Catalogue 1909-10. Charlottesville, 1910. (Gift of L. L. Holladay.)

UNITED ENGINEERING SOCIETY

Association of American Steel Manufacturers. Standard Specifications Governing the Allowable Variations in Size and Weight of Hot Rolled Bars, as adopted by the Association, 1910. n.p. n.d. (Gift of Association of American Steel Manufacturers.)

——Standard Specifications Governing the Chemical and Physical Properties of Bessemer Steel Rails, as adopted by the Association, May 24, 1906. N.p. n.d. (Gift of Association of American Steel Manufacturers.)

——Standard Specifications Governing the Chemical and Physical Properties of Concrete Reinforcement Bars as adopted by the Association, 1910. N.p. n.d. (Gift of Association of American Steel Manufacturers.)

——Standard Specifications Governing the Chemical and Physical Properties of Structural and Special Open-Hearth plate and Rivet Steel, as adopted by the Association, August 9, 1895, Revised Feb. 17, 1896, Oct. 23, 1896, April 19, 1902, and Feb. 6, 1903. (Gift of Association of American Steel Manufacturers.)

New International Year Book, 1909. New York, Dodd, Mead and Company, 1910. (Purchase.)

Statesman's Year-Book. 1910. London, Macmillan & Co., 1910. (Purchase.)

Steel Mine Timbers. Data and Tables for the use of Mining Engineers. Pittsburg, 1910. (Gift of Carnegie Steel Company.)

Surveyors' Institution. List of Members. 1910. Westminster, 1910. (Gift of Surveyors' Institution.)

OFFICERS AND BOARD OF DIRECTORS, 1910-1911.

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NOTE:—The Institute Constitution provides that the above named twenty-three officers shall constitute the Board of Directors.

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*FRANKLIN L. POPE, 1886–7.
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FRANK J. SPRAGUE, 1892–3.
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FRANCIS B. CROCKER, 1897–8.
A. E. KENNELLY, 1898–1900.
CARL HERING, 1900–1.
CHARLES P. STEINMETZ, 1901–2.
CHARLES F. SCOTT, 1902–3.
BION J. ARNOLD, 1903–4.
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SCHUYLER S. WHEELER, 1905–6.
SAMUEL SHELDON, 1906–7.
HENRY GORDON STOTT, 1907–8.
LOUIS A. FERGUSON, 1908–09.
LEWIS BUCKLEY STILLWELL 1909-10

*Deceased.

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W. G. T. GOODMAN,
Adelaide, South Australia.

ROBERT J. SCOTT,
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Term expires July 31, 1911.
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Baltimore.........Dec. 16, '04	J. B. Whitehead.	L. M. Potts, 107 East Lombard St., Baltimore, Md
Boston............Feb. 13, '03	J. F. Vaughan.	Harry M. Hope, 147 Milk Street, Boston, Mass.
Chicago..................1893	J. G. Wray.	E. N. Lake, 181 La Salle St., Chicago, Ill
Cleveland.........Sept. 27, '07	A. M. Allen.	Howard Dingle, 912 N. E. Building, Cleveland, Ohio.
Fort Wayne.......Aug. 14, '08	E. A. Wagner.	J. V. Hunter, Fort Wayne Electric Works, Ft. Wayne, Ind
Ithaca............Oct. 15, '02	E. L. Nichols.	B. C. Dennison, Cornell University Ithaca, N. Y.
Los Angeles.......May 19, '08	J. A. Lighthipe.	J. E. MacDonald, 444 P. E. Bldg., Los Angeles, Cal.
Madison ....Jan. 8, '09	M. H. Collbohm	H. B. Sanford, Univ. of Wisconsin, Madison, Wis.
Mexico ....Dec. 13, '07	E. Leonarz.	Gustavo Lobo, Cadena Street, No. 2, Mexico, Mex.
Milwaukee....... Feb. 11, '10	W. H. Powell.	L. L. Tatum, Cutler-Hammer Mfg. Co., Milwaukee, Wis.
Minnesota.........Apr. 7, '02	J. C. Vincent	J. H. Schumacher, 2716 University Ave., Minneapolis, Minn
Norfolk............Mar. 13, '08		R. R. Grant, P. O. Box 254, Norfolk, Va
Philadelphia.......Feb. 18, '03	C. I. Young.	H. F. Sanville 608 Empire Building, Philadelphia, Pa
Pittsburg..........Oct. 13, '02	C. B. Auel.	E. B. Tuttle, C. D. & P. Tel. Co., Pittsburgh, Pa
Pittsfield..........Mar. 25, '04	S. H. Blake.	W. C. Smith, General Electric Company, Pittsfield, Mass.
Portland, Ore......May 18, '09	L. B. Cramer,	F. D. Weber, 559 Sherlock Building, Portland, Ore.
San Francisco.....Dec. 23, '04	George R. Murphy.	S. J. Lisberger, 445 Sutter St., San Francisco, Cal.
Schenectady.......Jan. 26, '03	M. O. Troy	R. H. Carlton, Gen. Elec. Co., Schenectady, N. Y.
Seattle............Jan. 19, '04	A. A. Miller.	W. S. Hoskins, 1428 21st Avenue, Seattle, Wash
St. Louis..........Jan. 14, '03	George W. Lamke.	F. W. L. Peebles, Chemical Building, St. Louis, Mo.
Toledo............June 3, '07	M. W. Hansen.	Geo. E. Kirk, 1649 The Nicholas, Toledo, O
Toronto...........Sept. 30, '03	H. W. Price.	W. H. Eisenbeis, 1207 Traders' Bank Bldg., Toronto, Can
Urbana...........Nov. 25, '02	Charles T. Knipp.	J. M. Bryant, 610 West Oregon St., Urbana, Ill.
Washington, D. C...Apr. 9, '03	Earl Wheeler.	H. B. Stabler, 1214 I St., Washington, D. C.

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Agricultural and Mechanical College of Texas	Nov. 12, '09	V. H. Braunig.	R. T. Shiels, A. and M. Col. of Tex., College Sta., Texas
Arkansas, Univ. of	Mar. 25, '04	W. B. Stelzner.	F. S. White, 523 Willow St., Fayetteville, Ark
Armour Institute	Feb. 26, '04	W. G. Tellin.	E. H. Freeman, Armour Inst. Tech., Chicago, Ill
Bucknell University	May 17, '10	C. N. Brubaker.	A. J. Huston, Bucknell University, Lewisburg, Pa.
Case School, Cleveland	Jan. 8, '09	S. G. Boyd.	Don C. Orwig, 2171 Cornell Road, Cleveland, Ohio.
Cincinnati, Univ. of	Apr. 10, '08	C. R. Wylie	Ralph B. Kersay, 315 Jackson St., Carthage, Ohio
Colorado State Agricultural College	Feb. 11, '10	Alfred Johnson.	D. E. Byerley, 229 N. Loomis Street, Fort Collins, Colo.
Colorado, Univ. of	Dec. 16, '04	Ernest Prince.	R. B. Finley, University of Colorado, Boulder, Colo.
Iowa State College	Apr. 15, '03	Frank K. Shuff.	
Iowa, Univ. of	May 18, '09	H. E. Scheark	A. H. Ford, University of Iowa, Iowa City, Ia.
Kansas State Agr. Col	Jan. 10, '08	R. E. Talley.	B. F. Eyer, 513 Fremont St., Manhattan, Kansas
Kansas, Univ. of	Mar. 18, '08	V. S. Foster.	R. L. Ponsler, Univ. of Kansas, Lawrence, Kans
Lehigh University	Oct. 15, '02	H. H. Fithian.	Jacob Stair, Jr., Lehigh University, Bethlehem, Pa
Lewis Institute	Nov. 8, '07	J. C. Johnson.	A. H. Fensholt, Lewis Institute, Chicago, Ill.
Maine, Univ. of	Dec. 26, '06	A. T. Childs.	J. P. King, University of Maine, Orono, Maine.
Michigan, Univ. of	Mar. 25, '04	E. B. McKinney.	Gerald J. Wagner, 454 S. First St., Ann Arbor, Mich.
Missouri, Univ. of	Jan. 10, '03	H. B. Shaw.	A. E. Flowers, Univ. of Missouri, Columbia, Mo
Montana State Col	May 21, '07	C. C. Kennedy.	J. A. Thaler, Montana State College, Bozeman, Mont.
Nebraska, Univ. of	Apr. 10, '08	Geo. H. Morse.	V. L. Hollister, Station A, Lincoln, Nebraska
New Hampshire Col	Feb. 19, '09	C. E. Hewitt.	L. W. Bennett, New Hampshire College, Durham, N. H.
North Carolina Col. of Agr. and Mech. Arts	Feb. 11 '10	Wm. H. Browne, Jr.	E. B. Moore, N.C.C.A. and M.A., West Raleigh, N.C.
Ohio State Univ	Dec. 20, '02	H. W. Leinbach.	F. L. Snyder, 128 E. Blake Ave., Columbus, Ohio.
Oregon State Agr. Col	Mar. 24, '08	E. R. Shepard.	W. Weniger, Ore. State Agricul. College, Corvallis, Ore.
Penn. State College	Dec. 20, '02	C. M. Wheeler.	J. M. Spangler, Penn. State College, State College Pa.
Purdue Univ	Jan. 26 '03	C. F. Harding.	H. T. Plumb, Purdue University, Lafayette, Ind
Rensselaer Polytechnic Institute	Nov. 12, '09	E. D. N. Schulte	W. J. Williams, Rensselaer Poly. Institute, Troy, N. Y.
Stanford Univ	Dec. 13, '07	T. W. Snell.	J. H. Leeds, Stanford University, California
Syracuse Univ	Feb. 24, '05	W. P. Graham.	A. R. Acheson, Syracuse University, Syracuse, N. Y.
Texas, Univ. of	Feb. 14, '08	B. E. Kenyon	J. A. Correll, University of Texas, Austin, Tex
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Washington Univ	Feb. 26, '04	Geo. W. Pieksen.	
Worcester Poly. Inst.	Mar. 25, '04	W. C. Greenough.	H. E. Hartwell, Worcester Poly. Inst., Worcester, Mass.

Total, 31

PROCEEDINGS

OF THE

American Institute

OF

Electrical Engineers.

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Vol. XXIX October, 1910 No. 10

October Meeting, A.I.E.E.

The two hundred and fifty-second meeting of the American Institute of Electrical Engineers, marking the opening of the season of 1910–1911, will be held in the Engineers' Building, 33 West 39th Street, New York City, on Friday evening, October 14, 1910. A paper entitled "Potential Strength of Dielectrics" will be presented by Messrs. Harold S. Osborne, of the American Telephone and Telegraph Company, and Harold Pender, professor of theoretical and applied electricity, Massachusetts Institute of Technology, Boston, Mass. The paper is printed in this issue of the PROCEEDINGS, beginning on page 1593.

Public Engineering Meeting in New York, October 17, 1910

A public engineering meeting will be held in the Engineers' Building, 33 West 39th Street, New York City, on Monday evening, October 17, 1910, at 8:00 p.m. Engineers who are members of other societies are invited to attend and participate in the discussion. The subject to be discussed is the "Rapid Transit Requirements of Greater New York" and will be presented in an informal paper by Mr. Frank J. Sprague, past-president, and chairman of the railway committee of the American Institute of Electrical Engineers. A brief statement will be given of the general facts pertaining to routes, and construction and equipment of the existing and proposed subways, illustrated by lantern slides. As the meeting is to be an informal one, intended to afford opportunity for the expression of engineering views upon a subject of great importance, the proceedings will not necessarily form any part of the published records of the Institute, but the discussions, with the assent of the speakers, may be published in a separate pamphlet.

Future Section Meetings

CHICAGO

A joint meeting of the Chicago Section in coöperation with the Electrical Section of the Western Society of Engineers will be held on October 19. Dr. C. P. Steinmetz, of Schenectady, will present a paper on "Industrial Importance of Electrostatics and Electric Impulse Forces." This will be the first joint meeting in Chicago for the season of 1910-1911.

FORT WAYNE

The October meeting of the Fort Wayne Section will be in the form of an inspection trip of the transmission lines, power and sub-stations, and roadbed and interurban lines of the Fort Wayne Wabash Valley Traction Company. The members will be the guests of Mr. M. J. Kehoe, superintendent of lines, who will place his private car at their disposal for the occasion. It is planned to make the trip on Saturday, October 8, the car leaving Fort Wayne about noon, and returning late in the evening. This plan, however, may be modified later, and the trip will prob-

ably be postponed if the weather is very inclement.

PHILADELPHIA

The Philadelphia Section will hold its first meeting on October 10, probably at the Engineers' Club, Philadelphia. Mr. H. C. Snook will present a paper entitled "Kathode Particles and Some Experiments with Them." As Mr. Snook will illustrate his talk with experiments, the paper promises to be one of unusual interest.

PITTSBURG

The October meeting of the Pittsburg Section will be held on Tuesday evening, October 11, in the auditorium of the Engineers' Society, Oliver Building, Pittsburg. The subject will be a discussion of the paper by Messrs. H. G. Stott and J. S. Pigott, entitled "Test of a 15,000-Kw. Steam-Engine Turbine Plant.", read at New York on March 8, 1910, and appearing in the September issue of the PROCEEDINGS. The paper will be discussed by engineers interested in the design and operation of both the steam and electrical ends of such a plant. The November meeting will be held at the same hour and place on November 8.

St. Paul Conservation Congress

The second national conservation congress was held at Saint Paul Minn., September 5, 6, 7 and 8. The American Institute of Electrical Engineers was represented by a complete delegation of five, consisting of W. B. Jackson, Chicago, chairman, Morgan Brooks of Urbana, Ill., E. P. Burch and A. W. Leonard of Minneapolis, and Ralph W. Pope of New York. At a conference of the delegates it appeared that any possible technical features of the congress would be overshadowed by the political questions, which were introduced by the advocates of state versus federal control of streams and forests. This state of affairs led to an improvised conference of all technical delegates who could be reached, called by Isham Randolph of Chicago. The conference was organized on September 7, with Mr. Randolph as chairman and Mr. Pope as secretary. Twenty-eight civil, mechanical, electrical, mining and chemical engineers, surveyors and architects responded to the call. Sub-committees were appointed to prepare resolutions bearing upon the five subjects recommended by the congress for consideration by the resolutions committee of the congress. The resolutions of the technical delegates on water, minerals, forests, lands and vital resources were accordingly transmitted to the general committee on resolutions for the information of that body, through the courtesy of Cyrus C. Babb, of Augusta, Maine, a Member of the American Society of Civil Engineers, who was a state delegate and a member of the resolutions committee of the congress. At the closing session, September 8, John Wallace, of Des Moines, Iowa, was elected president. The time and place of the next congress, will be fixed by the executive committee.

Testimonial to Dr. Rossiter W. Raymond

On April 30, 1910, a dinner was given to Dr. Rossiter Worthington Raymond, Secretary of the American Institute of Mining Engineers, in commemoration of his seventieth birthday. A report of the congratulations and addresses on that occasion has recently been issued in the shape of a beautifully illustrated leather-bound brochure, a copy of which has been presented to the American Institute of Electrical Engineers.

Representatives from the American Institute of Mining Engineers, Ingeneurs Civils de France, Iron and Steel Institute, Institution of Mining and Metallurgy, Canadian Mining Institute, Mining Society of Nova Scotia, American Society of Mechanical Engineers, American Institute of Electrical Engineers, American Society of Civil Engineers, and other technical societies

were among the speakers on this occasion, who paid honor to Dr. Raymond's long and illustrious professional career. A number of brief addresses from his friends in many walks of life also testify to the high esteem in which he is held as a man as well as a scientist.

On this occasion a handsome silver table-service was presented to Dr. and Mrs. Raymond, on which are engraved various medallions representing different activities in Dr. Raymond's versatile career, also the seals of many societies of which he is an honorary member, and of the universities which have conferred honorary degrees upon him.

Applications for Election

Applications have been received by the Secretary from the following candidates for election to membership in the Institute as Associates. These applications will be considered by the Board of Directors at a future meeting. Any Member or Associate objecting to the election of any of these candidates should so inform the Secretary before October 25, 1910.

9677 Allison, L. W., Los Angeles, Cal.
9678 Goodell, W. S., Chicago, Ill.
9679 Hoyt, F. W., Fort Wayne, Ind.
9680 Losey, G. H., Kokomo, Ind.
9681 Marshall, E., St. Paul, Minn.
9682 Silvernail, F. D., No. Tonowanda, N. Y.
9683 Dierck, R. E. F., Buenos Aires, A. R.
9684 Marshall, V. R., Dillon, Colo.
9685 Edwards, H., Dunedin, N. Z.
9686 Scott, J. H., Dunedin, N. Z.
9687 Charles, W., Detroit, Mich.
9688 Gouty, M. B., Fort Wayne, Ind.
9689 Berkeley, L. R., Cleveland, O.
9690 Monahan, J. G., Toronto, Ont.
9691 Mooney, F. P., San Bernardino, Cal.
9692 North, F. S., Bay Shore, L. I.
9693 Paul, Charles A., Bridgeport, Conn
9694 Nicht, A. J., Jr., Milwaukee, Wis.
9695 Temple, H. A., New York City.
9696 Turner, E. P., Christchurch, N. Z.
9697 Johnson, C. B., San Francisco, Cal.
9698 Nichols, F. M., Organno, S. India.
9699 Norsa, Renzo, New York City.
9700 Perrin, G. L., Rhyolite, Nevada.
9701 Jenkins, M. O., Elizabeth, N. J.
9702 McManus, E. F., Pittsburg, Pa.
9703 Pridham, E. S., Stanford University, Cal.
9704 Schaaf, D. L., San Francisco, Cal.
9705 Spencer, R. H., Los Angeles, Cal.
9706 Jones, J. D., Philadelphia, Pa.
9707 Christenson, O., So. Wellfleet, Mass.
9708 Fairly, G. E., Sauqus, Cal.
9709 Newcomb, L. L., Bishop, Cal.
9710 Nussbaum, V. M., Fort Wayne, Ind.
9711 Savant, J. J., Baroda, India.
9712 Boyd, W. B., Toronto, Ont.
9713 Osborne, H. S., New York City.
9714 Stearns, R. W., Schenectady, N. Y
9715 Brown, R. P., Philadelphia, Pa.
9716 Stafford, A., San Francisco, Cal.
9717 Cobb, R. M., Los Angeles, Cal.
9718 Gain, L. D. A., Vancouver, B. C.
9719 Jerauld, R. E., Salt Lake City, Utah.
9720 Lancaster, J. G., New York City.

Total, 44.

Applications for Transfer

The following Associates were recommended for transfer at the meetings of the Board of Examiners held on June 22 and July 12, 1910. Any objection to the transfer of these Associates should be filed at once with the secretary.

JOSEPH HAROLD LIBBEY, Mechanical and Electrical Engineer, Stone and Webster Engineering Corporation, Boston, Mass.

LEWIS LITTLEPAGE HOLLADAY, Associate Professor of Electrical Engineering, University of Virginia, Charlottesville, Va.

WILLIAM NELSON MOTTER, Electrical Engineer, Allis-Chalmers Company, Milwaukee, Wis.

KALMAN VON KANDO, Managing Director, Societa Italiana Westinghouse, Vado Ligure, Italy.

CLARK T. HENDERSON, Electrical Engineer, Cutler-Hammer Mfg. Company, Milwaukee, Wis.

CLARENCE E. DOOLITTLE, Consulting Hydraulic and Electrical Engineer and V.P. and Gen. Mgr., Roaring Fork Electric Light and Power Company, Aspen, Colo.

OLIN JEROME FERGUSON, Assistant Professor of Electrical Engineering, Union College, Schenectady, N. Y.

Past Section Meetings

MEXICO

The Mexico Section held a meeting at the American Club, City of Mexico, on August 2, 1910. The subject of the meeting was a paper by Professor Francisco Uriquidi, of the National School of Mines, entitled "Engineering Education." Professor Uriquidi described in detail the course designed by him for the electrical engineering students in the Mexican National School of Engineers. The proposed course is based upon Professor Karapetoff's concentric method, great stress being laid upon the practical work done by the students, both in the shops of the schools, and in the various electrical industries in the vicinity. In every case the theoretical investigation of a subject is undertaken after the student has become thoroughly familiar with the manner in which the principles involved are put into use in modern commercial practice.

The following meeting of the Section was held at the Mexican Herald Club on September 2, 1910. Mr. Donald J. Hutton read a paper on "Illumination." The paper covered the general principles of the art, and concluded with some information in regard to the illumination of public and private buildings during the celebration of the anniversary of Mexican independence which took place in September. The magnitude of this illumination may be realized from the fact that there were in use on the buildings about 135,000 10-watt tungsten lamps, and about 50,000 30-watt incandescent lamps, all of which were situated in the central portion of the city, within a very limited area. The discussion that followed brought out some interesting information regarding the various methods of connecting these temporary installations.

PITTSBURG

The Pittsburg Section held its first meeting for this season on September 13, 1910. Over 100 members were present. The following officers were elected: Chairman, H. N. Muller, secretary, Ralph W. Atkinson; executive committee, the chairman and secretary, and Messrs. Ludwig Hommel, L. F. Howard, L. R. Palmer, E. P. Vankirk, K. C. Randall, R. S. Feicht. It was voted to hold meetings this year in the assembly room of the Engineers Society of Western Pennsylvania, Oliver Building, Pittsburg, Pa. The technical program consisted of the following papers: "Ability of Modern Electric Locomotives to Perform Heavy Service", by F. E. Wynne; "High Spots in Mechanical Design of Modern Electric Locomotives", by G. M. Eaton; "Feeder Regulators", by E. E. Lehr; "Connections of Instrument Transformers", by A. P. Bender.

TOLEDO

Mr. William E. Wickenden, assistant professor of electrical engineering at the Massachusetts Institute of Technology, Boston, Mass., addressed the members of the Toledo Section at their opening meeting, held on September 2, 1910. In his opening remarks Mr. Wickenden called attention to this being the centennial of Sir Humphrey Davy's experiments with the first electric lamp, in which platinum was heated to incandescence. The first carbon filament lamp in a vacuum was tried out in 1838, but it is only in recent years that the industry has developed to its present magnitude. The increase in lighting efficiency by the use of new metal filament lamps, taking tungsten as an example, was stated to be comparable to an increase in engine efficiency of 150 per cent. With carbon

filament lamps only about 0.20 of one per cent of the energy of coal is effective as an illuminant, while with tungsten this is raised to 0.50 of one per cent. Tungsten filament of drawn wire is now in the course of development, which will result in uniformity in texture, and a strength greater than that of steel, making possible in the near future a lamp not only of greater efficiency than carbon, but of much longer life. Lantern slides were used to supplement explanations of various points brought out in the lecture. A general discussion followed by Messrs. Horan, Neuber, Gilmartin, Nickels, and Kirk.

Personal

MR. L. CLYDE CHATFIELD has resigned from the construction department of the Edison Electric Illuminating Company, Brooklyn, N. Y., and will return to England.

MR. RALPH BENNETT, formerly of Los Angeles, is now with the Great Western Power Company, Shreve Building, San Francisco, Cal., as engineer on new developments.

MR. CHARLES H. KEEL, of the patent department of the General Electric Company, Schenectady, N. Y., has been transferred to the Washington, D. C. office of the company.

MR. F. J. DOMMERQUE has left the Stromberg-Carlson Telephone Manufacturing Company, Rochester, N. Y., and is now with the Western Electric Company, New York City.

MR. SYDNEY W. ASHE, consulting engineer and educator, is at present engaged in educational work at the Harrison Lamp works of the General Electric Company.

CAPTAIN C. DEF. CHANDLER, Signal Corps, U. S. A., has been transferred from Washington, D. C., to Leavenworth, Kansas, where he is taking a course at the Army Service Schools.

MR. FOSTER VEITENHEIMER has changed his address from Fishers Island, N. Y., to 39 Whitehall Street, New York City, in care of the chief signal officer, Department of the East.

MR. W. P. HOLCOMBE, for five years engineer of the Frank Adam Electric Company, has resigned to enter the St. Louis office of Allis-Chalmers Company, as sales engineer.

MR. H. A. STANLEY has left the turbine construction department of the General Electric Company at Schenectady to take up engineering work in the Boston office of the same company.

MR. CHARLES E. ANDERSON, formerly with the Western Electric Company, has accepted a position in the engineering department of the New York Edison Company, 55 Duane Street, New York City.

MR. J. J. MARTINDALE, former chief engineer for the Northern Construction Company, Jackson, Mich., has been appointed electrical engineer of the Michigan United Railways Company, Jackson, Mich.

MR. THOMAS D. LOCKWOOD and Mrs. Lockwood sailed from Boston on September 14, by steamship Canopic, for Genoa and Naples. They will be abroad for a little over a month, returning via England.

MR. ETIENNE DE FODOR, general manager of the Budapest General Electric Company, has been honored by Emperor Francis Joseph I of Austria and Hungary, in recognition of scientific services rendered.

MR. L. DE VEREBELY has resigned his position in the power engineering department of the Westinghouse Electric and Manufacturing Company and returned to Europe to work along theoretical lines.

Mr. Earle Jackson Banta, chief engineer of the Ohio Steam Shovel and Dredge Company, Cincinnati, Ohio, has resigned to accept a similar position with the Vulcan Steam Shovel Company, Toledo, Ohio.

Mr. Thomas W. Wilkinson resigned from the Kansas City Home Telephone Company on August 1 to accept a position in the plant department of the Missouri and Kansas Telephone Company, Kansas City, Mo.

Mr. Joseph W. L. Hale has resigned as instructor in electrical engineering at the Pennsylvania State College to take charge of the school for apprentices of the Pennsylvania Railroad Company at Altoona, Pa.

Mr. W. C. Wagner, chief engineer of the Northwestern Improvement Company, at Ravensdale, Wash., has been granted ten months' leave of absence to enable him to accept the Sibley fellowship at Cornell University.

Mr. W. E. Harkness, formerly sales engineer with the Western Electric Company, in charge of railroad and competitive engineering, has resigned to accept the position of assistant general manager of the United States Electric Company, 284 Pearl Street, New York City.

Mr. R. W. Shoemaker, consulting and contracting electrical engineer, has opened an office in Los Angeles, Cal. Mr. Shoemaker has just completed the installation of the first commercial trackless trolley in America, to be operated in Laurel Canon, near Los Angeles.

Mr. W. G. Taylor has resigned from the testing department of the General Electric Company at Schenectady to accept a position with the New York and Queens Electric Light and Power Company of Long Island City, N. Y.

Mr. Walter G. Mullen, of Baltimore, Md., has accepted a position with the Mortkrum Printing Telegraph Company, as their eastern representative, with headquarters at 253 Broadway, in care of the Postal Telegraph Company.

Mr. John C. Potter, who for three years has been in the traffic department of the American Telephone and Telegraph Company, has resigned to enter the electrical engineering department at Purdue University, Lafayette, Ind.

Mr. Theodore N. Vail, president of the American Telephone and Telegraph Company, has given a sufficient sum of money for the establishment of a secondary school of agriculture in connection with Lyndon Institute, Lyndon, Vermont.

Mr. Howard D. Carpenter, for several years instructor in electrical engineering at the University of Missouri, has accepted a position with the North Shore Electric Company, Chicago. His mailing address is 5404 Monroe Avenue.

Mr. Arthur W. Townsley was recently transferred from the instrument transformer engineering department of the General Electric Company at Lynn, Mass., to the power transformer engineering department at the Pittsfield works.

Mr. J. M. Barr, manager of the industrial motor department of the Westinghouse Electric and Manufacturing Company, has resigned his position to become manager of works for the Fairbanks-Morse Electrical Manufacturing Company, Indianapolis, Ind.

Mr. P. T. Bammes, for three years chief electrician for the Boston Consolidated Mining Company at Garfield, Utah, has left that company, and is now engaged in construction work for

the Intermountain Electric Company, of Salt Lake City, Utah.

MR. PHILIP S. BIEGLER has left the Washington Water Power Company, of Spokane, Wash., and removed to West Lafayette, Ind., to take the position in Purdue University left vacant by Professor Plumb, who is now on leave of absence for one year.

MR. ROBERT W. ADAMS, of the transformer engineering department of the General Electric Company at Pittsfield, has been transferred to the district office of the company at 84 State Street, Boston, Mass., as sales engineer in the power and mining department.

MR. JOSEPH A. OSBORN, electrical engineer for the American Car and Foundry Company, announces a change of his address from Lincoln Trust Building, to 915 Olive Street, St. Louis, Mo., the company having removed its offices to the latter location.

MR. JOHN LINN MCKIM YARDLEY has been transferred from the Buffalo office of the erecting department of the Westinghouse Electric and Manufacturing Company to the power division of the engineering department of the same company at East Pittsburg.

MR. W. R. SORENSEN, who for several years has been with the General Electric Company, doing exeprimental work and designing large power transformers, is now in charge of the department of electrical engineering at Throop Polytechnic Institute, Pasadena Cal.

MR. TRYGVE JENSEN has accepted the position of assistant in the engineering experiment station in the University of Illinois, Urbana, Ill. For the last year Mr. Jensen has been assistant engineer with the Shawinigan Water and Power Company at Montreal, P. Q.

MR. DAVID R. SHEARER, formerly drafting engineer with the Tennessee Copper Company, Copperhill, Tenn., is now engineer and estimator for the Acme Electric Company, 702 South Gay Street, Knoxville, Tenn. He also has an office at 611 South Third Street, Knoxville.

MR. HUGH A. BROWN has been appointed manager of the Chicago office of the Garwood Electric Company, with offices at 555 Old Colony Building. During the last eight years Mr. Brown has been actively engaged in the sale of electrical machinery in Chicago and Cincinnati.

MR. J. S. S. COOPER has resigned from the British Westinghouse Company, London, to accept a position with Samuel McGregor and Company, of China, with headquarters in Shanghai, China. He expects to leave England in the latter part of October, traveling via Siberia.

MR. G. A. HARVEY, electrical engineer, formerly with the International Railway Company of Buffalo, N. Y., is assisting Mr. Horatio A. Foster, who is associated with Mr. Bion J. Arnold, on valuation work in connection with the Southern California Edison Company, of Los Angeles, Cal.

MR. WILL SPALDING, formerly construction engineer with the Portland Railway, Light and Power Company, at Portland, Oregon, has purchased an interest in the Tillamook Electric Light and Fuel Company, Tillamook, Oregon, and has been appointed general manager of the company.

MR. WILLIAM W. HANDY, who for a number of years has been engaged in electric light, power and railway work in the East and South, has been appointed assistant engineer on special work for the Pittsburg Railways Company and the Allegheny County Light Company at Pittsburg, Pa.

Mr. L. J. Corbett has established his office in the new Realty Building at 244 Riverside Avenue, Spokane, Wash., opposite the Washington Theatre, where he will continue his general engineering consultation practice conducted in the Empire State Building, Spokane for the past four years.

Mr. A. W. McLimont, for the last year and a half general manager for the receivers of the Chicago and Milwaukee Electric Railroad Company, Highwood, Ill., has been appointed vice-president and general manager of the Michigan United Railways Company. The change took effect on June 1.

Mr. P. J. Kearny, assistant to the electrical engineer of the New York, New Haven and Hartford Railroad Company, at New Haven, Conn., has been appointed engineer in charge of electric traction on the New York, Westchester and Boston Railway, with headquarters at Mount Vernon, N. Y.

Mr. J. P. Moore, formerly instructor in electric railway engineering at the Pennsylvania State College, is again with Mr. Robert P. Woods, consulting and constructing engineer, of Indianapolis, as electrical engineer, and is now engaged on a large irrigation project at Roswell, New Mexico.

Mr. H. L. Beach, until recently operating engineer with the Pennsylvania Coal and Coke Company, of Cresson, Pa., has joined the engineering department of the Westinghouse Electric and Manufacturing Company, East Pittsburg. Mr. Beach will be connected with the design of control apparatus for induction service.

Mr. J. Rae Wilson, who resigned as superintendent of the Middlecreek Electric Company, of Sunbury, Pa., in November, 1909, to take charge of the installation of apparatus in the 110,000-volt-sub-station built by the Hydroelectric Power Commission of Ontario, is now with the Canadian Westinghouse Company at Niagara Falls South, Ontario.

Mr. Phinehas V. Stephens recently resigned his position as electrical and mechanical engineer with Mr. William T. Donnelly, consulting engineer, 135 Broadway, New York City, to accept a similar position in the engineering and construction department of the Safety Insulated Wire and Cable Company, 114 Liberty Street, New York City.

Mr. Walter S. Rodman has been appointed adjunct professor of electrical engineering at the University of Virginia. Mr. Rodman was formerly instructor in electrical engineering at the Rhode Island College, and for the past two years has been taking a post graduate course in electrical engineering at the Massachusetts Institute of Technology.

Mr. Walter T. Peck, who until recently had offices at 2 Rector Street New York City, is now with the Cuban agents of the General Electric Company, Sussdorff, Zaldo and Company, Havana, Cuba, who also represent the Wheeler Condenser and Engineering Company and other prominent American and European manufacturers of engines, boilers, pumps, and sugar machinery.

Mr. Robert B. Bonney re-entered the employ of the Colorado Telephone Company, at Denver, Colo., on April 25, 1910, as assistant equipment engineer, after several years of work in other lines of electrical engineering. Mr. Bonney was with this company for 12 years previous to November 1907.

Mr. Perry O. Crawford, who had charge of the installation of the Inskip power house for the Northern California Power Company, of San Francisco, which was placed in operation on July 1, 1910, has been transferred to the Colman power house site, where he will

have charge of the power house construction. The capacity of Inskip is 6,000 kw., and that of Colman will be 15,000 kw.

MR. R. P. KINCHELOE, JR., has accepted the position of assistant chief engineer of the South Covington and Cincinnati Street Railway Company and the Union Light, Heat and Power Company, with headquarters at Newport, Ky. Mr. Kincheloe was formerly with the General Electric Company, in the power and mining engineering department at the Schenectady works.

MR. LOUIS F. LEUREY having completed the electrical installation at the Bay Shore step-down transforming station of the Sierra and San Francisco Power Company at San Francisco, has been transferred by the engineers, Sanderson and Porter, to Vancouver Island, B. C., to install the electrical apparatus of the Jordan River development for the Vancouver Island Power Company.

MR. WILLIAM G. DAVIS, who has been at his home in Washington, D. C., for some time attending to affairs following his father's death, has returned to New York City, and is now attached to the New York office of the United States Light and Heating Company, as storage battery sales engineer. Mr. Davis was formerly manager of the New York office of the Westinghouse Storage Battery Company.

MR. J. F. BRATNEY, chief engineer of the Bell Telephone Company of Missouri at St. Louis, has resigned to become superintendent of plant for the Missouri and Kansas Telephone Company at Kansas City, Mo. Mr. Bratney has been with the Bell Telephone Company of Missouri for the last seven years.

HENRY FLOY, consulting engineer, has been retained by the Montreal Light, Heat and Power Company, as expert, in connection with their suit against the City of Montreal to recover $250,000 claimed to be due on account of city lighting. The company has been serving the city for eighteen months without any definite agreement as to the price to be paid for arc and incandescent lighting, and the matter is now before a board of arbitration.

MR. WALTER I. SLICHTER has left the General Electric Company to become professor of electrical engineering at Columbia University. Mr. Slichter entered the employ of the General Electric Company in 1896, on his graduation from Columbia University. For several years he was closely associated with Dr. C. P. Steinmetz, and was also a member of the railway and traction department under Mr. W. B. Potter. More recently he was technical assistant to Dr. E. W. Rice, vice-president and chief engineer of the General Electric Company.

DR. EDWIN F. NORTHRUP has been appointed assistant professor of physics at Princeton University. He will make a specialty of physical and electrical measurements, and plans to conduct researches in this line. Dr. Northrup will keep in close touch with outside electrical affairs, and where it will not conflict with his university duties he expects to act as a consultant in matters relating to engineering work on the side of electrical measurements. In the higher science of electrical measurements Dr. Northrup probably has no superior in this country.

Obituary

GEORGE NIAL EASTMAN died at Riverside, Cal., on June 14, 1910. Mr. Eastman was born in Arkona, Ontario, Canada, on December 10, 1874. At an early age he moved to Michigan, where he attended school at Fort Gratiot and Imlay City. He graduated from high school at the latter place in 1891. A year later he became a student in the mechanical engineering

department of the Michigan Agricultural College, graduating in 1897 with the degree of Bachelor of Science. Early in 1898 he entered the employ of the Chicago Edison Company, in the construction department, and in September 1899 was given charge of the testing laboratory. About five years ago Mr. Eastman's health failed, and after an extended tour through Europe, he went to California, where he has since resided. He became an Associate of the Institute on November 22, 1901. Mr. Eastman was the author of a number of valuable papers on various technical subjects.

FREDERICK F. GARDNER, general manager of the Shore Electric Company, of Red Bank, N. J., was found dead near the tracks of the Central Railroad of New Jersey, six miles from Red Bank, on September 8, 1910. Mr. Gardner was born in Clifton Springs, N. Y., on August 22, 1865. When a young man he became connected with the Bergen County Gas and Electric Company, as manager of its Englewood branch, and when this company was taken over by the Public Service Corporation Mr. Gardner was retained in his old position. Four years ago he left there to take charge of the Shore Electric Company. Recently he was superintending the erection of a new power plant in the southern limits of Red Bank. He was elected an Associate of the Institute on January 29, 1904. He is survived by his widow and an infant son.

Library Accessions

The following accessions have been made to the Library of the Institute since the last acknowledgment.

American Institute of Electrical Engineers. Transactions. Vol. XXVIII, pts. 1–2. Jan.–Dec., 1909. (Gift of A.I.E.E.)

Armour Institute of Technology. Bulletin of General Information. May, 1910. Chicago, 1910. (Gift of Armour Institute of Technology.)

Electric Motors, Their Action, Control and Application. By. F. B. Crocker and Morton Arendt. New York, D. Van Nostrand Co., 1910. (Gift of publishers.) Price, $2.50 net.

CONTENTS:—Chapter I.—Introduction. II.—Types of Motors and Advantages of Electric Drive. III.—Action of Shunt Motors. IV.—Shunt-Motor Starting Boxes. V.—Shunt-Motor Speed Control by Variation of Armature Voltage. VI.—Speed Control of Shunt Motors by Variation of Field Current. VII.—Speed Control of Motors of Variation of Field Reluctance. VIII.—Multiple-Voltage Systems of Motor Speed Control. IX.—Direct-current Series Motors. X.—Control of Direct-current Series Motors. XI.—Compound-wound Motors. XII.—Alternating-current Motors—Introduction. XIII.—Synchronous Alternating Current Motors. XIV.—Polyphase Induction Motors. XV.—Starting of Polyphase Induction Motors. XVI.—Speed Control of Polyphase Induction Motors. XVII.—Single-phase Induction Motors. XVIII.—Commutating Alternating-current Motors. XIX.—Service Conditions and Applications of Electric Motors. Appendix A.—Standardization Rules Electric Motors.

Electrical Trades Directory and Handbook. 1910. London, 1910. (Purchase.)

Manual of Electrical Undertakings and Directory of Officials, 1910. Vol. 14. By E. Garcke. London, 1910. (Purchase.)

Objects of Tests and Investigations at Underwriters' Laboratories. (An Address Delivered at the Annual Convention of the International Association of Fire Engineers, Syracuse, N. Y., Aug. 1910.) By W. H. Merrill. (Gift.)

Society of Engineers. Its origin and aims. London, 1910. (Gift of Society of Engineers.)

Universal Electrical Directory. 1910. By J. A. Berly. London, 1910. (Purchase.)

Trade Catalogues

Allis-Chalmers Co., Milwaukee, Wis. Bulletin No. 1054. Allis-Chalmers steam turbines and generators. 43 pp.

Municipal Engineering. Vols. 22–23. New York, 1902. (Exchange.)

Sanitary Engineer. Vols. 12,16. New York, 1885, 1887. (Exchange.)

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SAMUEL SHELDON, 1906-7.
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LEWIS BUCKLEY STILLWELL 1909-10

*Deceased.

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Baltimore.........Dec. 16, '04	J. B. Whitehead.	L. M. Potts, 107 East Lombard St., Baltimore, Md
Boston............Feb. 13, '03	J. F. Vaughan.	Harry M. Hope, 147 Milk Street, Boston, Mass.
Chicago.................1893	J. G. Wray.	E. N. Lake, 181 La Salle St., Chicago, Ill.
Cleveland.........Sept. 27, '07	A. M. Allen.	Howard Dingle, 912 N. E. Building, Cleveland, Ohio.
Fort Wayne.......Aug. 14, '08	E. A. Wagner.	J. V. Hunter, Fort Wayne Electric Works. Ft. Wayne, Ind
Ithaca............Oct. 15, '02	E. L. Nichols.	George S. Macomber, Cornell University Ithaca, N. Y.
Los Angeles.......May 19, '08	J. A. Lighthipe.	J. E. MacDonald, 444 P. E. Bldg., Los Angeles, Cal.
Madison ....Jan. 8, '09	M. H. Collbohm	H. B. Sanford, Univ. of Wisconsin, Madison, Wis.
Mexico...........Dec. 13, '07	E. Leonarz.	Gustavo Lobo, Cadena Street, No. 2, Mexico, Mex.
Milwaukee........Feb. 11, '10	W. H. Powell	L. L. Tatum, Cutler-Hammer Mfg. Co., Milwaukee, Wis.
Minnesota.........Apr. 7, '02	J. C. Vincent	J. H. Schumacher, 2716 University Ave., Minneapolis, Minn
Philadelphia.......Feb. 18, '03	C. I. Young.	H. F. Sanville 608 Empire Building, Philadelphia, Pa
Pittsburg..........Oct. 13, '02	H. N. Muller.	Ralph W. Atkinson, Standard Underground Cable Co., 16th & Pike Sts., Pittsburgh, Pa.
Pittsfield..........Mar. 25, '04	S. H. Blake.	W. C. Smith, General Electric Company, Pittsfield, Mass.
Portland, Ore......May 18, '09	L. B. Cramer,	F. D. Weber, 559 Sherlock Building, Portland, Ore.
San Francisco.....Dec. 23, '04	George R. Murphy	S. J. Lisberger, 445 Sutter St., San Francisco, Cal.
Schenectady.......Jan. 26, '03	E. A. Baldwin.	W. E. Reece, Foreign Department. Gen. Elec. Co., Schenectady, N. Y.
Seattle............Jan. 19, '04	A. A. Miller	W. S. Hoskins, 1428 21st Avenue, Seattle, Wash
St. Louis..........Jan. 14, '03	George W. Lamke.	F. W. L. Peebles, Chemical Building, St. Louis, Mo.
Toledo............June 3, '07	M. W. Hansen	Geo. E. Kirk, 1649 The Nicholas, Toledo, O.
Toronto...........Sept. 30, '03	H. W. Price.	W. H. Eisenbeis, 1207 Traders' Bank Bldg., Toronto, Can
Urbana...........Nov. 25, '02	Charles T. Knipp.	J. M. Bryant, 610 West Oregon St., Urbana, Ill
Washington, D.C..Apr. 9, '03	Earl Wheeler.	H. B. Stabler, 1214 I St., Washington, D. C

Total, 24

LIST OF BRANCHES.

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Agricultural and Mechanical College of Texas	Nov. 12, '09	V. H. Braunig.	R. T. Shiels, A. and M. Col. of Tex., College Sta., Texas
Arkansas, Univ. of	Mar. 25, '04	W. B. Stelzner.	F. S. White, 523 Willow St., Fayetteville, Ark.
Armour Institute	Feb. 26, '04	W. G. Tellin.	E. H. Freeman, Armour Inst. Tech., Chicago, Ill.
Bucknell University	May 17, '10	C. N. Brubaker.	A. J. Huston, Bucknell University, Lewisburg, Pa.
Case School, Cleveland	Jan. 8, '09	S. G. Boyd.	Don C. Orwig, 2171 Cornell Road, Cleveland, Ohio.
Cincinnati, Univ. of	Apr. 10, '08	C. R. Wylie.	Ralph B. Kersay, 315 Jackson St., Carthage, Ohio
Colorado State Agricultural College	Feb. 11, '10	Alfred Johnson.	D. E. Byerley, 229 N. Loomis Street, Fort Collins, Colo.
Colorado, Univ. of	Dec. 16, '04	Ernest Prince.	R. B. Finley, University of Colorado, Boulder, Colo.
Iowa State College	Apr. 15, '03	Frank K. Shuff.	Ralph R. Chatterton, Iowa State College, Ames, Iowa.
Iowa, Univ. of	May 18, '09	H. E. Scheark.	A. H. Ford, University of Iowa, Iowa City, Ia.
Kansas State Agr. Col.	Jan. 10, '08	R. E. Talley.	B. F. Eyer, 513 Fremont St., Manhattan, Kansas.
Kansas, Univ. of	Mar. 18, '08	V. S. Foster.	R. L. Ponsler, Univ. of Kansas, Lawrence, Kans.
Lehigh University	Oct. 15, '02	H. H. Fithian.	Jacob Stair, Jr., Lehigh University, Bethlehem, Pa.
Lewis Institute	Nov. 8, '07	J. C. Johnson.	A. H. Fensholt, Lewis Institute, Chicago, Ill.
Maine, Univ. of	Dec. 26, '06	A. T. Childs.	J. P. King, University of Maine, Orono, Maine.
Michigan, Univ. of	Mar. 25, '04	E. B. McKinney.	Gerald J. Wagner, 454 S. First St., Ann Arbor, Mich.
Missouri, Univ. of	Jan. 10, '03	H. B. Shaw.	A. E. Flowers, Univ. of Missouri, Columbia, Mo.
Montana State Col	May 21, '07	Harry Peck.	J. A. Thaler, Montana State College, Bozeman, Mont.
Nebraska, Univ. of	Apr. 10, '08	Geo. H. Morse.	V. L. Hollister, Station A, Lincoln, Nebraska.
New Hampshire Col	Feb. 19, '09	C. E. Hewitt.	L. W. Bennett, New Hampshire College, Durham, N. H.
North Carolina Col. of Agr. and Mech. Arts	Feb. 11 '10	Wm. H. Browne, Jr.	E. B. Moore, N.C.C.A. and M.A., West Raleigh, N.C.
Ohio State Univ.	Dec. 20, '02	H. W. Leinbach.	F. L. Snyder, 128 E. Blake Ave., Columbus, Ohio.
Oregon State Agr. Col.	Mar. 24, '08	E. R. Shepard.	W. Weniger, Ore. State Agricul. College, Corvallis, Ore.
Penn. State College	Dec. 20, '02	C. M. Wheeler.	J. M. Spangler, Penn. State College, State College, Pa.
Purdue Univ	Jan. 26 '03	C. F. Harding.	H. T. Plumb, Purdue University, Lafayette, Ind
Rensselaer Polytechnic Institute	Nov. 12, '09	E. D. N. Schulte.	W. J. Williams, Rensselaer Poly. Institute, Troy, N. Y.
Stanford Univ	Dec. 13, '07	T. W. Snell.	J. H. Leeds, Stanford University, California
Syracuse Univ	Feb. 24, '05	W. P. Graham.	A. R. Acheson, Syracuse University, Syracuse, N. Y
Texas, Univ. of	Feb. 14, '08	B. E. Kenyon.	J. A. Correll, University of Texas, Austin, Tex
Wash., State Col. of	Dec. 13, '07		M. K. Akers, State Col. of Wash., Pullman, Wash.
Washington Univ	Feb. 26, '04	Geo. W. Pieksen.	
Worcester Poly. Inst.	Mar 25, '04	W. C. Greenough.	H. E. Hartwell, Worcester Poly. Inst., Worcester, Mass.

Total, 31

PROCEEDINGS

OF THE

American Institute

OF

Electrical Engineers.

Published monthly at 33 W 39th St., New York, under the supervision of

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Vol. XXIX **November, 1910** No. 11

November Meeting A. I. E. E.

The two hundred and fifty-third meeting of the American Institute of Electrical Engineers will be held in the auditorium of the Engineers' Building, 33 West 39th Street, New York City, on Friday evening, November 11, 1910. A paper entitled "Interpoles and Synchronous Converters" will be presented by Messrs. B. G. Lamme and F. D. Newbury, both of the Westinghouse Electric and Manufacturing Company, Pittsburg, Pa. The paper is printed in this issue of the PROCEEDINGS.

The John Fritz Medal Public Meeting for the Presentation of the Medal for 1910

The John Fritz Medal was established by the professional associates and friend of John Fritz, Honorary Member American Society of Civil Engineers, of Bethlehem, Pa., on August 21, 1902, his eightieth birthday, to perpetuate the memory of his achievements in industrial progress. The medal is awarded by a Board of sixteen, made up in equal numbers from the membership of the American Society of Civil Engineers, the American Institute of Mining Engineers, the American Society of Mechanical Engineers, and the American Institute of Electrical Engineers. It is awarded for notable scientific or industrial achievement, and there is no restriction on account of nationality or sex.

Awards of this medal to date have been made as follows:

The first (1905) to LORD KELVIN "for his work in cable telegraphy and other scientific attainments."

The second (1906) to GEORGE WESTINGHOUSE "for the invention and development of the air brake."

The third (1907) to ALEXANDER GRAHAM BELL "for the invention and introduction of the telephone."

The fourth (1908) to THOMAS ALVA EDISON "for the invention of the duplex and quadruplex telegraph; the phonograph; the development of a commercially practical incandescent lamp; the development of a complete system of electric lighting, including dynamos, regulating devices, underground system protective devices and meters."

The fifth (1909) to CHARLES T. PORTER "for his work in advancing the knowledge of steam engineering and in improvements in engine construction."

The medal for 1910 has been awarded to ALFRED NOBLE, past-president, American Society of Civil Engineers, "for notable achievements as a civil engineer," and will be presented at a meeting to be held at the house of the American Society of Civil Engineers on the evening of Wednesday, November 30, 1910, at 8.30 p.m. All members of the four national societies above named, and all others interested, are invited to be present.

Dr. Samuel Sheldon, past-president, American Institute of Electrical Engineers, now president of the Board of Award, will preside, and addresses will

be made by Isham Randolph, Member American Society Civil Engineers, of Chicago, Dr. R. W. Raymond, secretary of the American Institute of Mining Engineers, and others.

Future Section Meetings

Pittsfield

The Pittsfield Section is planning to hold meetings every two weeks during this season. It is proposed to reserve every second meeting for outside speakers, and the alternate meetings for local speakers. At the time of going to press with this issue, the first so-called "local meeting" was to have been held on October 27, and the following meeting will probably be held during the week beginning November 7. The following speakers have already been secured for this year: Dr. C. P. Steinmetz, Schenectady, N. Y., Dr. W. S. Franklin, Lehigh University, Professor H. E. Clifford, Harvard University, and Mr. W. D'A. Ryan.

Toronto

The November meeting of the Toronto Section will be held in the rooms of the Engineers' Club, 96 King Street West, on November 11, 1910. A paper will be presented by Mr. H. H. Morrell, of the Tate Accumulator Company, entitled "Storage Batteries."

Washington, D. C.

The Washington Section will hold its November meeting in the Telephone Building, at 8:00 p.m., Tuesday, November 8, 1910. The subject will be "Searchlights", and the speakers will be Commander S. S. Robison, U. S. Navy, and Lieutenant William H. Rose, Corps of Engineers, U. S. Army.

Mexico

The Mexico Section will hold its next regular meeting on November 4, 1910. A paper will be presented by Mr. T. R. Bremner, entitled "Gas Engine Design and Operation."

Portland, Oregon

The Portland Section has prepared a schedule of papers for its next four meetings, to be presented by the respective authors. The program as now arranged is as follows:

November 15, 1910—Subject, *High Tension Transmission*, by H. R. Wakeman, of the Portland Railway, Light and Power Company.

December 13, 1910—Subject, *Railway*, by W. H. Evans, of the Southern Pacific Company.

January 17, 1911—Subject, *Conservation of Natural Resources*, by E. J. Griffith.

February 21, 1911—Subject, *Telegraph and Telephone Work*, by E. L. Ritter, of the Pacific Telephone and Telegraph Company.

Directors' Meeting, October 14, 1910

The regular monthly meeting of the Institute Board of Directors was held at 33 West 39th Street, New York City, on Friday, October 14, 1910. The directors present were: President Dugald C. Jackson, Boston, Mass.; Past-president Lewis B. Stillwell, New York; vice-presidents Paul Spencer, Philadelphia, Pa., P. M. Lincoln, Pittsburg, Pa., Percy H. Thomas, New York; managers, W. G. Carlton, New York, A. W. Berresford, Milwaukee, Wis., H. H. Barnes, Jr., New York, Severn D. Sprong, New York, David B. Rushmore, Schenectady, N. Y., Charles W. Stone, Schenectady, N.Y.; Treasurer George W. Hamilton, Elizabeth, N. J.; Secretary, Ralph W. Pope, New York.

Upon recommendation of the Meetings and Papers Committee the Board authorized the holding of a joint Institute meeting of the Schenectady-Pittsfield Sections early in February 1911.

Seventy-two candidates for admission to membership in the Institute as Associates were elected.

Seventy Students were declared enrolled.

Nine Associates were transferred to the grade of Member, as follows:

Lewis L. Tatum, Assistant Chief-Engineer, Cutler-Hammer Manufacturing Company, Milwaukee, Wis.

John B. Ingersoll, Chief Electrical Engineer, Spokane and Inland Empire Railroad Company, Spokane, Wash.

Arthur H. Timmerman, Chief Engineer, Wagner Electric Manufacturing Company, St. Louis, Mo.

Oliver C. Spurling, Plant Engineer, Western Electric Company, Hawthorne, Ill.

L. Frederic Howard, Electrical Engineer, Union Switch and Signal Company, Swissvale, Pa.

Arthur Simon, Electrical Engineer, Cutler-Hammer Manufacturing Company, Milwaukee, Wis.

Nathaniel A. Carle, Consulting Engineer, Seattle, Wash.

Francis A. Vaughn, Consulting Electrical Engineer, Vaughn and Meyer, Milwaukee, Wis.

William H. Powell, Electrical Engineer, Allis-Chalmers Company, Milwaukee, Wis.

Associates Elected October 14, 1910

Albert, John Carelton, Electrical Inspector, Pacific Electric Railway Co.; res., 2845 Council St., Los Angeles, Cal.

Alexander, Frank E., Electrical Engineer, Anaconda Copper Mining Co.; res., 441 Anaconda Road, Butte, Mont.

Arnold, Anthony Brown, Mechanical Engineer, The American Agricultural Chemical Society, 92 State St., Boston, Mass.

Barry, Edward James, Electrical Engineer, Potlatch Lumber Co., Potlatch, Idaho.

Barwise, Albert Harold Osborne, Electrical Engineer, Power House, Meerut, India.

Benjamin, Charles Love, Advertising Manager, Cutler-Hammer Mfg. Co.; res., 2518 Wells Street, Milwaukee, Wis.

Bowling, Victor Stanislaus, Manager, Shearer Electrical Construction Co., Avenida Juarez No. 38, Mexico City, Mex.

Boyce, Benjamin Knowlton, Telephone Engineer, New York Telephone Co., 15 Dey St.; res., 501 West 121st St., New York City.

Brantly, Edgar Clayton, Secretary and Treasurer, City Electric Co., Tuscaloosa, Alabama.

Brown, Leo, Construction Engineer, Canadian Westinghouse Co., Hamilton, Ont.

Bryden, Thomas William, Electrical Engineer, 24 Mitchell Avenue, Binghampton, N. Y.

Cahoon, William Hamblin, Inspector, N. Y, N. H. & H. R.R., Stamford; res., Locust St., Greenwich, Conn.

Caird, Harry, Manager Engine Department, Excello Arc Lamp Co., 617 West Jackson Blvd., Chicago, Ill.

Calland, Otho Glen, Electrical Engineer, Ohio Brass Co., Mansfield, Ohio.

Cheney, Herbert W., Engineer in Charge Electric Detail Dept., Allis-Chalmers Co., Milwaukee, Wis.

Clarke, Da Costa Moore, Electrician, Southern Railway Co., Asheville, N. C.

Clary, William Henry, General Superintendent, Divaas Electric Lighting Co., Round Lake, N. Y.

Collins, Percy Edward, Assistant to Superintendent of Construction, Northern Westchester Lighting Co.; res., 4 Terrace Ave., Ossining, N. Y.

Demmert, Otto, Superintendent, Watson Flagg Engineering Co., 27 Thames St., New York City.

Deutsch, Simon, Electrical Engineer, Electro-Mechanical Engineering Co., 503 Manhattan Bldg., Chicago, Ill.

Donald, James, Electrical Engineer, Municipal Electric Light & Water Works, Mooresville, N. C.

DUBILIER, WILLIAM, Wireless Engineer, Continental Wireless Telephone & Telegraph Co., 54 Clinton St., Newark, N. J.

EASTER, RODERICK RALPH, Operating Department, Seattle-Tacoma Power Co.; res., 915 East Fir St., Seattle, Wash.

EBMEIER, HENRY WILLIAM, Electrician, United States Navy, U.S.S. Vermont; res., Cincinnati, Ohio.

EDWARDS, LANCELOT, Shift Operator, Vancouver Power Co., Ltd., Lake Buntzen Power House, Burrand, B.C.

FLICKINGER, FRED GARFIELD, Electrical Construction Department, General Electric Co., 30 Church St., New York City.

FORBES, SHERMAN GUY, Station Engineer, Isthmian Canal Commission, Atlantic Division, Gatun, C. Z.

GOODSPEED, MEREDITH CLYDE, Electrical Engineer of Equipment & Maintenance, Pennsylvania General Electric Co. Erie, Pa.

GRIGSBY, REDMAN, WILLIAM, Washington, Consulting Engineer, 125 West Ave., 29, Los Angeles, Cal.

HARTWELL, ERNEST FRANCIS, Chief Electrician, with R. H. Simon, Union Hill; res., Homestead, N. J.

HADLEY, CLARENCE G., Electrical Engineer, National Electric Signaling Co., Brant Rock, Mass.

HAYNES, DELOS GARRIOTT, Assistant Examiner, U. S. Patent Office; res., 1440 Meridian St., Washington, D. C.

HILDENBRAND, HARRY, General Superintendent, L. C. Ehle Oil Mills, Houston, Texas.

HOON, CHARLEY LEWIS, Electrician, Los Angeles Aqueduct, Brown, Cal.

HOWARD, OLIVER AMHERST, Electrician, Navy Yard, Boston; res., 134 Garfield Avenue, Chelsea, Mass.

HUCH, OTTO FREDERICK, Assistant Chief Draughtsman, Union Electric Light and Power Co.; res., 809 Grand Ave., St. Louis, Mo.

HUTTON, DONALD JOHN, Illuminating Engineer, Mexican Light and Power Co., Mexico, D. F.

IZANT, GEORGE WALTER, Engineer, Westinghouse Electric & Mfg. Co.. 1004 New England Bldg., Cleveland, Ohio.

JONES, E. JESSE, General Superintendent, Florida Power Company, Ocala, Florida.

KIRCHGASSER, GEORGE JOHN, Assistant Advertising Manager, Cutler-Hammer Mfg. Co.; res., 3211 McKinley Blvd., Milwaukee, Wis.

KUNZMANN, HENRY LUDWIG, Master Electrician, Coast Artillery Corps, U.S.A., Fort Mills, Corregidor, P. I.

LEONARD, FRANK E., Construction Engineer, Geo. W. Jackson, Inc., 754 Jackson Blvd.; res., 4716 Racine Ave., Chicago, Ill.

LINDEMANN, FERDINAND, Electrical Engineer, Compania de Luz y Fuerze de Cordoba, Cordoba, Argentine Republic.

LYNCH, HENRY BAKER, Manager Lighting Department, City of Glendale; res., 313 Jackson St., Glendale, Cal.

NEWILL, GEORGE ERNEST, Mechanical and Electrical Engineer, Guadalupe Consolidated Mining Co., Inde, Durango, Mexico.

NISAR, ABDUR RAHMAN, Inspector Commonwealth Edison Co., 84 Market St.; res., 1523 W. Monroe St., Chicago, Ill.

NOYES, ARTHUR HAINES, Electrician, Snow Mountain Water & Power Co., Ukiah, Cal.

OFFUTT, M. WEBB, Vice President and General Manager, Schenectady Illuminating Co. and Mohawk Gas Co., Schenectady, N. Y.

PAGANO, CHARLES J., Inspector, Gould Storage Battery Co., The Rookery, Chicago, Ill.

PARKINSON, FLOYD WALDO, Salesman, Westinghouse Electric & Mfg. Co., 936 Metropolitan Life Bldg., Minneapolis, Minn.

PARSONS, WILLIAM NORMAN, Superintendent, Shearer Electric Construction Co., 38 Avenida Juarez, Mexico City, Mex.

PETERSEN, JOHN, Manager, Frank E. Harmon Co.; res., 445 Bidwell Ave., Portland, Ore.

PIRIE, JOHN H., 1st Lieutenant, Coast Artillery Corps, United States Army, Fort Dade, Florida.

POPPER, EUGENE, Shift Engineer in Charge, United Missouri River Power Co., Butte, Montana.

RIDDLE, DONALD WHARTON, Traveling Salesman, General Electric Co.; res., 4545 Morgan St., St. Louis, Mo.

RUTZ, EDWARD CHARLES, Electrical Engineer, Commissioners of Lincoln Park, Lincoln Park Power House, Chicago, Ill.

RYAN, JOHN JULIUS, Electrician, W. A. Jackson, Old Colony Bldg.; res., 4459 Prairie Ave., Chicago, Ill.

SESHASAYEE, R., Principal, Institute of Electrical & Mechanical Engineering, Teppekulam, S. India.

SMITH, PERD O., Sales Department, Fort Wayne Electric Works; res., 525 West Jefferson Street, Fort Wayne, Indiana.

STACK, GEORGE EDWARD, Electrical Engineer, General Electric Co.; res., 21 Furman St., Schenectady, N. Y.

STAGE, ROY C., Operating Electrician, Elmira Water, Light & Railroad Co.; res., 909 Hoffman St., Elmira, N. Y.

STEELMAN, JOHN CLARENCE, Electrical Engineer, Texarkana Gas and Electric Co., Texarkana, Tex.

STERRETT, JOHN ADLUM, Springland, Pierce Mill Road, Washington, D. C.

TAYLOR, ALBERT LE ROY, Laboratory Assistant, University of Utah; res., 435 B. Street, Salt Lake City, Utah.

THERRELL, DANIEL MACLAUCHLIN, Assistant General Superintendent of Traffic, Southern Bell Tel. & Tel. Co., Atlanta, Ga.

TIMMERMAN, HARRY ERNEST, Electric Contractor, Seymour Power & Electric Co., Campbellford, Ont.

TOBIAS, DAVID FRANCIS, Test Engineer, Edison Storage Battery Co., Orange, N. J.; res., 132 West 126th St., New York City.

VON KANDO, KALMAN, Electrical Engineer, Societa Italiana Westinghouse, Vado Ligure, Italy.

WALDORF, FRED, Mechanical Engineer, with A. B. Newmann, 1122 Rookery Bldg., Chicago, Ill.

WATSON, MCCLELLAND BARRY, Engineering Apprentice, Canadian Westinghouse Co., Ltd.; res., 134 Cannon St. E., Hamilton, Can.

WRENN, HENRY BRADLEY PLANT, Electrical Locomotive Engineer, Detriot River Tunnel Co., Detroit, Mich.

YRIGOYEN, PEDRO JUAN, Electrical Engineer, with Mr. Enrique Schondube, Mexico City, Mex.

Applications for Election

Applications have been received by the Secretary from the following candidates for election to membership in the Institute as Associates. These applications will be considered by the Board of Directors at a future meeting. Any Member or Associate objecting to the election of any of these candidates should so inform the Secretary before November 25, 1910.

9721 Burt, H. A., Denver, Colo.
9722 Pratt, O. G., New York City.
9723 Hogshead, C. C., Roanoke, Va.
9724 Miller, C. H., Milwaukee, Wis.
9725 Enfield, W. L., Cleveland, Ohio.
9726 Menefoglio, A., Kauai, H. I.
9727 Braun, H. H., Hidalgo, Mex.
9728 Otis, A. N., Schenectady, N. Y.
9729 Woltz, F. I., St. Louis, Mo.
9730 Beveridge, W. B., Salt Lake City.
9731 Blaisdell, J. L., Portland, Ore.
9732 Hammond, R. C., Kingston, Ont.
9733 Kahl, G. C., Schenectady, N. Y.
9734 Rathbun, R. B., Coram, Cal.
9735 Stevens, E. R., Schenectady, N. Y.
9736 Tenney, R. B., Jr., Schenectady.
9737 Tressler, M. E., Pittsfield, Mass.
9738 Vaitses, G. S., Melrose, Mass.
9739 Finch, F. R., Pittsfield, Mass.
9740 Johnson, W. C., San Francisco, Cal.
9741 Munsell, T. S., Batavia, N. Y.
9742 Phipps, F. A., Seattle, Wash.
9743 Raymond, A. A., Jersey Shore, Pa.
9744 Stewart, A. B., Mexico City, Mex.

9745 Utz, A. L., St. Joseph, Mo.
9746 Whitstone, R. A., Jr., Phila., Pa.
9747 Dickenson, W. J., Schenectady, N.Y.
9748 Hall, M. S., Saltville, Va.
9749 Hardcastle, H. K., Wilkinsburg, Pa.
9750 Hill, Joseph S., Washington, D. C.
9751 Reyneau, P. O., Ithaca, N. Y.
9752 Sawford, F., Sydney, N. S.
9753 Smith, C. O., Los Angeles, Cal.
9754 Snyder, J. C., Altoona, Pa.
9755 West, J. S., Queensland, Aus.
9756 Hess, W. F., Pittsburg, Pa.
9757 Day, E. W., Watertown, Mass.
9758 Glynn, A. J., Pittsburg, Pa.
9759 Parker, W. D., Pittsburg, Pa.
9760 Rand, E. W., Battle Creek, Utah.
9761 Drummond, A. J., Chicago, Ill.
9762 Giffney, T. A., Chicago, Ill.
9763 Hale, J. C., New York City.
9764 Hartman, F. S., New York City.
9765 Harper, S. P., Pittsfield, Mass.
9766 Hynes, F. B., Newark, N. J.
9767 Pentecost, C. B., Nashville, Tenn.
9768 Pierce, C. A., Ithaca, N. Y.
9769 Woodward, M. Q., Pine Bluff, Ark.
9770 Cummings, H. L., Jr., Schenectady.
9771 Hoover, P. P., Edgewater, Colo.
9772 McManus, J. H., New York City.
9773 Osborn, S. R., New York City.
9774 Reed, Taylor, Schenectady, N. Y.
9775 Taylor, C. B., Philadelphia, Pa.
9776 Thomas, P., Princeton, N. J.
9777 Thomas, Phillips, Princeton, N. J.
9778 Collins, B. W., Tacoma, Wash.
9779 Hendricks, A. B., Pittsfield, Mass.
9780 Tyng, Arthur, Boston, Mass.
9781 Wickham, C. H., Adelaide, So. Australia.
9782 Matte, A. L., Springfield, Mass.
9783 Neary, E. J., Philadelphia, Pa.
9784 Woodward, J. G., Redondo, Cal.
9785 Crawford, W. S., Seattle, Wash.
9786 Hudson, W. F., New York City.
9787 Sipher, E. G., Lumberton, N. C.
9788 Brand, F. F., Pittsfield, Mass.
9789 Smith, H. H., Orange, N. J.

Total, 69.

Applications for Transfer

The following Associates were recommended for transfer at the meeting of the Board of Examiners held on October 14, 1910. Any objection to the transfer of these Associates should be filed at once with the secretary.

PHILIP J. KEARNY, Assistant to Electrical Engineer, N. Y., N. H. and H. R.R., New Haven, Conn.

MURRAY C. BEEBE, Professor of Electrical Engineering, University of Wisconsin, Madison, Wis.

Students Enrolled October 14, 1910

3791 Lundquist, A. J., State Univ. of Ia.
3792 Putnam, K. S., State Univ. of Iowa.
3793 Walter, R. E., Iowa State College.
3794 Benbow, F. M., Iowa State Col.
3795 Stewart, B. J., Iowa State Col.
3796 Moss, V. W., Iowa State Col.
3797 Palmer, B. L., Iowa State Col.
3798 Gilmore, C. B., Iowa State Col.
3799 Cooley, C. H., Iowa State Col.
3800 Huhn, C. G., Univ. of Penn.
3801 McGuire, W. P., Armour Inst. Tech.
3802 McCann, E. G., Stanford Univ.
3803 Ellis, Edw. M., Montana State Col
3804 Le Count, C. M., Stanford Univ.
3805 Talbaut, C. H., Stanford Univ.
3806 Wooster, R. N., Stanford Univ.
3807 Keesling, H., Stanford Univ.
3808 Nimmo, L. C., Stanford Univ.
3809 Leeds, J. H., Stanford Univ.
3810 Johnson, A. E., Colo. Agri. Col.
3811 Kerlin, S. B., Purdue Univ.
3812 Hormats, M., Rensselaer Poly. Inst.
3813 McKaig, A. W., Rennsselaer Poly. Inst.
3814 Woodcock, E. C., Stanford Univ.
3815 Wenk, M., Stanford Univ.
3816 Greene, B. H., Purdue Univ.
3817 Elstun, W. M., Purdue Univ.
3818 Spielman, M. H., Purdue Univ.
3819 Shute, E. R., Purdue Univ.
3820 Yenne, R. V., Purdue Univ.
3821 Brady, J. B., Purdue Univ.
3822 Kane, M., Purdue Univ.
3823 Lebeau, F. J., Purdue Univ.
3824 Elliott, G. M., Purdue Univ.
3825 McNeal, R. L., Purdue Univ.
3826 Cavanaugh, F. L., Purdue Univ.
3827 Fox, G. H., Purdue Univ.
3828 McIntosh, J. A., Purdue Univ.
3829 Wilson, R. M., Purdue Univ.
3830 Markus, H. F., Purdue Univ.
3831 Billingsley, C. H., Purdue Univ.

3832 Lane, E. W., Purdue Univ.
3833 Shettel, W. R., Purdue Univ.
3834 McKinzie, L. H., Purdue Univ.
3835 Goldsmith, F. C., Purdue Univ.
3836 Gault, F. E., Purdue Univ.
3837 Royer, R. E., Purdue Univ.
3838 Kellams, W. W., Purdue Univ.
3839 Appel, G. C., Purdue Univ.
3840 Collen, M., Purdue Univ.
3841 Barker, J. D., Purdue Univ.
3842 Doud, H. P., Purdue Univ.
3843 Maish, C. A., Purdue Univ.
3844 Frank, M. H., Purdue Univ.
3845 Pittman, C. F., Purdue Univ.
3846 Beardsley, C. S., Purdue Univ.
3847 Kunse, R., Purdue Univ.
3848 Bopp, D. C., Purdue Univ.
3849 Blakeslee, H. H., Purdue Univ.
3850 McClure, J. A., Purdue Univ.
3851 Mertz, J. R., Purdue Univ.
3852 Curtner, D. L., Purdue Univ.
3853 Schuman, E. S., Purdue Univ.
3854 Kroeger, F. C., Purdue Univ.
3855 Hansel, F. M., Purdue Univ.
3856 Hawker, P. H., Purdue Univ.
3857 Irvin, R. L., Purdue Univ.
3858 Cook, J. C., Purdue Univ.
3859 Spring, H. E., Purdue Univ.
3860 Armstrong, R. S., Purdue Univ.

Problems in Design and Operation of Very Large Electrical Generating Systems

By C. P. Steinmetz

Very large systems of a few years ago can now hardly be classed as of medium size. A 1,000-light generator, that is, of approximately 100 h.p. capacity, was a monster machine only a few years ago. Now we are designing 20,000 h.p. units. The size of generators gradually grew larger and larger, but as the cities took up this new power the growth was so rapid that many systems were obliged to tie in with others, making the regulation of the voltage on the lights very poor. Then the multiple voltage and the three-wire systems came into use. The three-wire system aided wonderfully in giving better regulation, but it was due to the modern alternating current systems that electric lighting became so successful. This was not without a bitter fight, however, between the direct and alternating current advocates, which lasted for many years. The alternating-current systems had a sad history, due largely to the fact that there were then no alternating-current motors, and therefore practically no load on the system during the day. This was costly. The frequencies used at that time were too high, being 125 and 133 cycles per second. It was realized, however, that there were vast possibilities in the alternating-current system. At this period, the rotary converter, which changes direct into alternating current, or vice versa, made its appearance. A combination of the alternating and direct-current systems was first tried out on a large scale by the New York Edison Company, and then by the Chicago system with a double current generator. The direct current was used near the station and distributed from three-wire mains, while the outlying districts were supplied with 3-phase, 25-cycle current at 6,600 and 13,200 volts. This alternating current was transformed at the generators to 6,600 or 13,200 volts and then re-transformed at suburbs to low voltages, and connected to rotary converters, giving three-wire direct current as near the station. As these stations developed in size the question naturally arose as to the limiting size of an economical station. Calculations were made showing that this limit was from 10,000 to 20,000 kw. These calculations were, however, based on one character of load. If a station has a very varied load, such as light, power, and railway, there is practically no limit to the economical size which can be built. Mr. Insull, of Chicago particularly brought out this argument and was willing to try it in the Fisk Street Station in Chicago, one of the largest in America. This station now has connected up 180,000 kw., equal to almost 250,000 h.p. On such large

*Abstract of lecture at a meeting of the Pittsfield Section of the A. I. E.E. on October 13, 1910.

systems, problems arise which are very difficult of solution and which were not even heard of in the smaller stations where the voltages were low, capacities limited, and the net-work and bus bars were of comparatively high resistance. There are high-frequency disturbances on the lines all the time, and enormous capacities behind any break-down. In fact, with a modern turbine station not equipped with special reactance coils for limiting the current, if a short circuit should occur at the bus bars, and the normal rating of the station were 250,000 h.p., there might be concentrated for a moment at the point of short circuit over 12,000,000 h.p. Apparatus such as switches, circuit breakers, etc., can hardly be made to take care of such enormous powers and it has been found necessary to install reactance coils in each generator circuit and also in the bus bars between groups of generators. These reactances, in order not to saturate, or "lay down", on such enormous currents are constructed with non-magnetic cores. They are also subject to enormous mechanical strains, up to hundreds of tons, when the short circuit current is thrown upon them, so that their design is very difficult. A comparison of these disturbances to waves of water facilitates an understanding of this subject by the non-technical man. With a small body of water, it takes a hurricane to raise a wave of appreciable size; while on the ocean, even on calm days, there are always wave disturbances. The electric waves caused by switching, etc., may be of limited power, but when they meet an obstruction, just as is true with water waves, they may rise to unlimited heights or voltages, depending on the nature of the obstruction. It is for this reason that the end turns of high voltage transformers are more heavily insulated than the other turns. Owing to the damage resulting from enormous short circuit currents, it is now becoming customary to specify regulation by giving a limit to the short circuit current in terms of full load current, usually 15 times normal. Other difficult problems have arisen with the advent of our very large systems, and much time and effort is being spent on them, both by manufacturers and customers.

Lecture Course of the Stevens Engineering Society

The Stevens Engineering Society, which is affiliated with the American Society of Mechanical Engineers and which comprises a society of students of Stevens Institute, announces a course of lectures which will be delivered at Stevens Institute during the coming season.

October 18—*Membership in Engineering Societies*, by Alexander C. Humphreys, M.A., Sc. D., LL.D., President of Stevens Institute.

November 1—*The Design and Construction of a Central Power Station*, by Irving E. Moultrop, M.E.

November 15—*Art and the Engineer*, by James P. Heney, B.S., M.D.

November 22—*With Peary in the Arctic*, by Donald D. Macmillan, A.B., A.M.

November 29—*The Services of Chemistry in the Promotion of Public Welfare*, by Harvey W. Wiley, M.D., LL.D., Ph.D.

December 6—*The Story of an Island*, by Rossiter W. Raymond, Ph.D., LL.D.

December 20—*The Origin of Petroleum*, by David T. Day, Ph.D.

January 10—*The Kimberley Diamond Mines*, by Gardiner L. Williams, E.M., LL.D.

January 16—*The Development of the Railroad on the North American Continent*, by James Douglas, LL.D.

February 7—*The Catskill Water Supply Project*, by John Bensel, M.E.

February 14—*The Electric Furnace*, by Carl Hering, M.E.

February 20—*Reclamation*, by Frederick H. Newell, B.S.

March 7—*Metallography as Applied to Engineering*, by William Campbell, Sc.D., Ph.D.

March 21—*Radio Active Phenomena*, by A. Stanley MacKenzie, Ph.D.

April 4—*Illuminating Engineering*, by George E. Hulse, M.E.

The lectures are given at 4 p.m. on the days mentioned, and members of the society, alumni of the Institute, undergraduates and their friends, are welcome to attend.

New York Subway Situation

An informal public engineering meeting was held in the Engineering Societies Building, October 17, to discuss the rapid transit situation in Greater New York. The paper of the evening was presented by Mr. Frank J. Sprague and was discussed by Messrs. W. J. Wilgus, L. B. Stillwell, W. S. Murray, R. E. Dowling and T. K. Thomson.

Mr. Sprague outlined the early history of the traction commissions in New York City and discussed the proposed tri-borough route, which he claimed was mistakenly conceived and would result in disaster if its construction as now planned is carried out. He advocated a proposed Lexington Avenue and Seventh Avenue subway, which would constitute a natural H formation with the existing subway route, which could be operated as a single system with the present system and would afford maximum accomodation to the greatest number of people. This proposed route would afford direct North and South through travel on the East and West sides of the city and would tap the terminus of the New York Central, Harlem, and New Haven railroads and would also connect with the new station of the Pennsylvania and Long Island railroads and through the Hudson and Manhattan company, would make connections with Jersey City, Hoboken, and the Erie and Lackawanna stations.

Mr. Wilgus advocated in general the plans proposed by Mr. Sprague and laid special stress upon the useless expense of enlarging the subways for the accommodation of foreign cars. The proposed increase in size above that of the present tunnels he stated, would greatly increase the cost of construction, while the tunnels would then be too small for some of the standard trunk line cars. It was also pointed out that the admission of foreign cars would upset existing schedules and that the curves, platform heights, and other details of the proposed subway are not adapted to the use of foreign cars.

Mr. Stillwell also contended that the plans of the tri-borough system would involve a useless expenditure of money for tunnels too large for present cars and too small for foreign cars.

Mr. Murray advocated the use of larger tunnels for the reason that he considers that at some future time it will be of advantage to admit foreign cars to the subway system.

Mr. Dowling advocated the route connecting the upper East side with the lower West side as proposed by Mr. Sprague and stated that such a route would prove of great benefit to residents in these localities. He also contended that the increase in property values would go far toward paying the cost of the system.

Institute Meeting at New York, October 14, 1910

The two hundred and fifty-second meeting of the American Institute of Electrical Engineers was held in the auditorium of the Engineers' Building, 33 West 39th Street, New York City, on Friday evening, October 14, 1910. President Dugald C. Jackson presided, and called the meeting to order at 8:15 p.m. The Secretary announced that at the meeting of the Board of Directors held during the afternoon 72 Associates were elected, and nine Associates were transferred to the grade of Member. The names of the Associates elected and those transferred are printed elsewhere in this issue. The Secretary further announced that authorization had been granted by the Board of Directors at the afternoon meeting for the holding of a joint Institute meeting of the Schenectady-Pittsfield Sections early in February 1911. President

Jackson then opened the meeting, and in a brief address introduced Mr. Harold S. Osborne, of the American Telephone and Telegraph Company, who presented his paper entitled " Potential Strength in Dielectrics." The paper was discussed by Dr. J. B. Whitehead, Dr. A. S. McAllister, Mr. Milton Franklin, Dr. A. E. Kennelly, Professor W. S. Franklin, Messrs. H. W. Buck, W. I. Middleton, Henry Morse, T. D. Waring, H. W. Fisher, Ralph W. Atkinson, Percy H. Thomas, Carl J. Fechheimer, G. I. Rhodes, A. H. Pikler, C. P. Steinmetz and C. O. Mailloux.

Institute Meeting in Cooperation with Schenectady-Pittsfield Sections February, 1911

At the meeting of the Institute Board of Directors held on October 14, 1910, authorization was granted, upon the recommendation of the Meetings and Papers Committee, for the holding of a joint Institute meeting in coöperation with the Schenectady and Pittsfield Sections early in February 1911. The exact date has not yet been definitely decided upon. This meeting is to be on the same basis as the special Institute meetings at Charlotte and San Francisco last spring. Details will be announced in a subsequent issue of the Proceedings.

1911 Convention

At the meeting of the Institute Board of Directors held on October 14, 1910, President Dugald C. Jackson was authorized to appoint a special committee to consider and make recommendations as to the time and place of holding the next annual convention. Members desiring to offer suggestions may address Secretary Ralph W. Pope, 33 West 39th Street, New York City, who will transmit all communications to the committee.

Past Section Meetings

ATLANTA

The Atlanta Section held its first meeting for this season in the Equitable Building, Atlanta, on October 13, 1910. Fifty-two members and visitors were present. A paper on " Bituminous Gas Producers " was read by Mr. C. P. Wood, and led to an interesting discussion. Those taking part in the discussion were: Messrs. Burnell, Schoen, Seidell, Taliaferro, Wilder, and Wood.

CLEVELAND

The first meeting of the Cleveland Section was held in the rooms of the Cleveland Engineering Society on September 19, 1910, with Chairman Albert M. Allen presiding. No paper was presented, the meeting being of a general business nature. A committee on papers was appointed by the chairman, and plans for the ensuing year were discussed.

At the next meeting, held on October 17, Mr. G. S. Merrill, of the National Electric Lamp Company, reviewed a paper read by him before the Toronto Section on November 19, 1909, entitled " Tungsten Lamps ", which was published in the September, 1910 Proceedings. Mr. Merrill was assisted by other members of his company, who discussed various phases of the subject. The plans for the coming year will be announced at the November meeting.

FORT WAYNE

An innovation in the regular order of meetings was enjoyed by the members of the Section on Saturday, October 8, when, as guests of Mr. M. J. Kehoe, superintendent of light and power of the Fort Wayne Wabash Valley Traction Company, they made a trip to Lafayette over the lines of the company. The car " Lawton " was very kindly placed at their disposal, and the prospect of such an interesting trip brought

out an unusually large attendance. The car left Fort Wayne at 11 a.m. and proceeded rapidly southward until the town of Roanoke was reached, where a short stop was made to examine the substation at that point, containing rotary converter and transformer sets and a mercury arc rectifier system for town lighting. Attention was also called to the terminals and line practice on this transmission system, which are here very easily studied. The transmission line operated at 33,000 volts. Continuing southward, a discussion was started by the reading of Dr. Steinmetz's recent paper on "Insulation Against Electrical Impulse Forces", which was published in the *General Electric Review*. One other stop was made before reaching Lafayette. This was at the point of crossing with the Wabash Railway, where the party examined the brazed bonds, used on the rails, made of laminated copper strip and arranged to allow for contraction and expansion, and also inspected the derailing device which had been installed to prevent collisions at the crossing. At Delphi an open elevated open air-break switch on special tower construction was inspected. This switch is an important unit in the system, as it permits the separation at this point of the Lafayette or Fort Wayne power stations which usually operate in synchronism, feeding the whole line, and this switch insures light at Delphi should either one of the two power stations break down. Upon arrival at Lafayette the party immediately proceeded to the new Lafayette power station of the traction company, which was recently completed by the installation of a lot of new machinery and the rebuilding and resetting of all parts of the old plant. This work was done under the personal direction and supervision of Mr. Kehoe. The present capacity of the station is about 2,000 kw. composed of a number of different units—all standard types. The switching arrangements are very complete and all arrangements are most thorough for handling the various demands upon the system. The new boiler plant is especially well equipped for the elimination of hand labor and has a complete system for handling coal and ash, as well as the usual forms of mechanical stokers. At this point the party separated, some going over to visit the university and others visiting an artificial ice plant in the neighborhood. At 5:30 p.m. they reunited at the La Bohemia Cafe, and after dinner took the car for the return trip. The return was devoted principally to social amusements, except when a second stop was made at Delphi the party proceeded uptown for a brief inspection of the lighting results obtained at this place and also to make a more thorough examination of the sub-station, which was not inspected on the way down. The remainder of the trip was made without incident, the party arriving in Fort Wayne at 11 p.m., and disbanding after passing a vote of thanks to Mr. Kehoe for his hospitality and kind attentions during the day.

An enthusiastic audience was present at the opening meeting of the Fort Wayne Section on Thursday evening, September 15, held in the rooms of the Fort Wayne Commercial Club, where all the regular meetings will be held in the future. The main subject of the evening was a paper presented by Mr. E. A. Wagner on "Some Characteristic Curves of Transforming Apparatus", which dealt more particularly with those types of apparatus whose curves are the most advantageous in a commercial way. This was followed by an informal discussion of the conduct of municipally owned public utilities, a subject of unusual local interest at the present time.

Philadelphia

A meeting of the Philadelphia Section was held at the Engineers' Club, Philadelphia, on October 10, 1910. An address of welcome was made by the incoming chairman, Mr. Charles I.

Young. Dr. George A. Hoadley then presented his report of the annual convention of the Institute at Jefferson, N. H., which he attended as the representative of the Philadelphia Section, after which the appointment of the standing and special committees was announced. The technical program consisted of a paper by Mr. H. Clyde Snook, who gave an experimental lecture on " Kathode Rays." A discussion followed by Messrs. Hering, Hoadley, Bonine, Gibson, Palmer, Kershner, Tuttle, and Hornor. Seventy-four members attended the meeting.

PITTSBURG

The Pittsburg Section held its regular meeting on October 11. The technical program consisted of a discussion of the Institute paper by Messrs. Stott and Pigott, entitled " Test of a 15-000-kw. Steam-Engine-Turbine Unit ", printed in the September PROCEEDINGS. Mr. H. C. Fairbanks, of the General Electric Company, summarized the paper and led the discussion. Others who discussed the paper were, Messrs. E. D. Dreyfus and W. B. Flanders, of the Westinghouse Machine Company, W. L. Waters and F. W. Harris, of the Westinghouse Electric and Manufacturing Company, and R. F. Patterson. The discussion was illustrated by lantern slides. Approximately 120 members were present.

PITTSFIELD

Before an audience of 142 engineers, Dr. C. P. Steinmetz spoke for an hour and a half on the subject " Problems in the Design and Operation of Very Large Electrical Generating Systems." The lecture was given in the high school auditorium, Pittsfield, on the evening of October 13, and marked the opening of the season of 1910–1911 for the Pittsfield Section. An abstract of the lecture is printed elsewhere in this issue.

SCHENECTADY

The annual election of officers of the Schenectady Section for the current year took place on August 1, 1910, resulting in the following appointments: Honorary Chairman, C. P. Steinmetz; chairman, E. A. Baldwin; vice-presidents for one year, E. B. Merriam, W. I. Slichter, V. E. Goodwin; for two years, F. L. Kemp, O. J. Ferguson, R. H. Carlton; managers for one year, F. H. Gale, T. A. Worcester, W. Dalton, J. R. Craighead, G. R. Parker; for two years, J. A. Seede, H. Maxwell, M. W. Offutt, C. S. Van Dyke; secretary, W. A. Reece, assistant secretary, J. C. Close; treasurer, E. J. Cheney; assistant treasurer, R. C. Muir.

SEATTLE

Through the courtesy of Mr. Allen Ransom, the members of the Seattle Section held their September meeting at the Arctic Club on September 17. The meeting was preceded by a dinner at which 21 members were present. Plans were discussed for improving the attendance at future meetings and stimulating discussion. Chairman Miller appointed a committee to secure discussors of Dr. C. E. Magnusson's paper on " Synchronous Motors ", to be presented at the next meeting.

TOLEDO

Mr. Paul Horan, of the Toledo Railways and Light Company, addressed the members of the Toledo Section at its regular meeting on Friday evening, October 7, 1910, at the Y. M. C. A. building. Mr. Horan's subject was " Transformers." In his introductory remarks he explained the many forms and varied use of transformers. The questions of heat, hysteresis and eddy losses were next considered and illustrations given showing how these factors must be taken into account. The speaker discussed at some length, two, three and six-phase transformers, particularly as to the method of connecting them for attaining various ends, with suggestions regarding proper and improper arrangements of delta and star transformers. To more clearly bring out the points presented, black-

board sketches were used, supplemented by lantern slides of wiring diagrams. The talk brought out many points of practical value to the workman confronted with problems in alternating-current apparatus. A general discussion followed by Messrs. Nolan, Neuber, Hill and Kirk.

Toronto

The first meeting of the Section for 1910–1911 was held on Friday, October 21, in the rooms of the Engineers' Club, Toronto. There was a total attendance of 124 members, students and visitors. Officers for the ensuing year were elected as follows: Chairman, E. Richards; vice-chairman, A. L. Mudge; secretary, W. H. Eisenbeis. The other members of the executive committee elected were, F. A. Gabey, H. A. Moore, J. G. Jackson, A. E. Hibner. Immediately following the election of officers, the chairman introduced Mr. P. W. Sothman, chief engineer of the Hydro-Electric Power Commission of Ontario, who gave an interesting lantern slide talk describing in detail the more prominent features of the 110,000-volt hydroelectric transmission system of Ontario, with particular reference to the Toronto sub-station, where the voltage is stepped down to 12,000 volts for delivery to the municipality. After Mr. Sothman had concluded the reading of the paper, the meeting adjourned to the sub-station at the foot of Strachan Avenue, where the members were shown through the station, which is now rapidly nearing completion. The engineers of the Commission very kindly explained the various details of construction, and the advanced engineering connected with this undertaking was clearly evident to those present. The meeting was an enthusiastic one, the members showing a lively interest in the work in progress. A number of Institute members from Niagara Falls, Hamilton and other points in the near vicinity were among those in attendance.

A meeting of the Executive Committee of the Toronto Section was held on Friday, September 30, 1910, at the St. Charles Cafe, Toronto. The following members were present: H. W. Price, chairman, E. Richards, A. L. Mudge, R. G. Black, W. H. Eisenbeis, and R. S. Clarke. The secretary was instructed to communicate with the chairman of the Institute Committee on Intermediate Grade of Membership, to secure if possible a statement as to progress made by the committee. The papers committee reported that they had secured as speaker for the October meeting, Mr. P. W. Sothman, chief engineer of the Hydro-Electric Power Commission of Ontario, who would give a lantern slide lecture on the 110,000-volt Toronto sub-station of the commission, to be followed by a visit of the members to the station itself. The committee further reported that they also have papers in prospect for future meetings as follows: November, "Storage Batteries"; December, "Station Protective Devices"; January, "Grain Elevator Equipment" and "Pulp Mill Equipment"; February, "Heavy Electric Traction"; March, a general discussion of small industrial equipments. The secretary presented his annual report for the past year, which was read and accepted. Mr. R. J. Clarke, who is leaving Toronto permanently, tendered his resignation as a member of the committee, which was accepted with regret.

Urbana

The Urbana Section held its opening meeting on October 5, 1910, in the electrical laboratory of the University of Illinois. About 20 members were present. Officers for the year were elected as follows: Chairman, Professor Morgan Brooks; secretary, Professor J. M. Bryant. Plans were laid for pushing the activities of the Section for the current year, and to this end other committees will be appointed at the next meeting.

WASHINGTON, D. C.

The first fall meeting of the Washington Section was held in the Telephone Building, Washington, on October 11. The Section was fortunate in having as the speaker for this meeting, Mr. Charles F. Scott, consulting engineer of the Westinghouse Electric and Manufacturing Company, and past-president of the Institute, who, as the founder of the system of Sections and Branches, was able to give a most interesting talk on Institute matters in general, particularly as to the history, scope and functions of Sections and their status and work in relation to the Institute. At the close of Mr. Scott's talk, which also covered in a broad and interesting way, the fields of power, railway and illuminating achievement, there was considerable discussion on the mutual relations of the Sections and the Institute. In a brief business meeting following the discussion, Lieutenant William H. Rose, U. S. A., was elected to fill a vacancy on the executive committee.

Past Branch Meetings

UNIVERSITY OF ARKANSAS

The first fall meeting of the University of Arkansas Branch was held in the engineering building on October 11, 1910. Professor Ripley, of the physics department, gave a talk on glass, including a brief history of the industry of glass manufacture, and describing the special grades produced in various countries. He also explained the method of manufacturing the commercial product in a modern plant. The talk was followed by the election of officers, Professor W. B. Stelzner was elected chairman, and Mr. L. R. Cole secretary.

UNIVERSITY OF COLORADO BRANCH

A meeting of this Branch was held on September 21, 1910, with a total attendance of 33. After an address of welcome to the new students by Professor Jenkins, a talk on apprenticeship courses was given by Mr. F. Bliss.

The next meeting was held on October 5, with 64 members and visitors in attendance. An informal talk was given by Professor H. S. Evans, concerning large electrical manufacturing companies. Mr. O. E. Youtsey spoke of his practical experience during the summer vacation.

COLORADO STATE AGRICULTURAL COLLEGE

This Branch held its first meeting for the school year 1910–1911 in the electrical building on September 21, 1910. Plans were made for the coming year. It was decided to make the next meeting a reception to all the electrical students with a view to increasing the membership of the Branch.

KANSAS STATE AGRICULTURAL COLLEGE

The Kansas State Agricultural College Branch held its first meeting for the school year on September 30. Mr. Homer Sloan was elected chairman, and Mr. W. C. Lane secretary. Regular meetings will be held on the first Tuesday of each month.

UNIVERSITY OF KANSAS

A meeting of this Branch was held on October 12, 1910. The following officers were elected for the ensuing year: Chairman, F. P. Ogden; vice-chairman, F. C. Lynch; secretary, L. A. Baldwin; executive committee, G. C. Shaad, H. A. Hoffman, M. K. Thomen, and A. E. Crawford. Mr. F. C. Lynch gave a talk on moving and installing a 300 h.p. gas engine. Mr. William Caldwell told of his experience during the summer with a street railway company.

LEHIGH UNIVERSITY

The regular October meeting of the Lehigh University Branch was held in the physical laboratory on Tuesday,

October 11, 1910. It was decided to raise the amount of the annual dues from $1.75 to $2.00. After the business session Professor W. S. Franklin addressed the students on the advantages of being a member of the Branch, and urged the necessity of regular attendance at meetings. Mr. W. S. Herrmann then gave a talk on the construction and operation of the Detroit Edison Company's plant. This is a large turbine-driven power station at Delray, four miles from Detroit, and supplies the electrical power for that city. This includes the trolley lines, the Michigan Central tunnels, and shops and automobile factories. In conclusion Professor William Esty gave an outline of the work of the A. I. E. E., and spoke of the advantages of being a member of the Institute.

University of Missouri

The first meeting of this Branch for the school year was held on October 10, 1910. A third member of the executive committee was selected. The committee is now constituted as follows: T. S. Haddaway, E. W. Stapf, and F. P. Huston. An informal description of summer experiences was given by Messrs. C. K. Lee, E. W. Stapf, and C. S. Lynch.

North Carolina College of Agriculture and Mechanic Arts

This Branch has reorganized for this year, with the following officers: Chairman, William Hand Browne; secretary and treasurer, Lucius E. Steere, Jr.

Ohio State University

A meeting of this Branch was held in the engineering lecture room of the university on October 14, 1910. A committee was appointed to arrange a program for the year. It was voted to hold meetings on every other Friday of each month. Professor J. H. Hunt gave an informal talk.

Purdue University

The first meeting of the Purdue University Branch, held on Tuesday evening, September 27, was one of the largest and most enthusiastic in the history of the Branch, the total attendance numbering 206 members and visitors. Chairman W. J. Powers called the meeting to order and gave a short address on the advantages of membership in the Branch. He then called on Professor C. Francis Harding, who spoke on the same subject and gave an outline of the plans for the coming year. Professor A. N. Topping congratulated the men on the size of the gathering and urged coöperation as the best aid toward good work. Common interests, he said, made it imperative that students should gather together and talk over the advances in their profession. Professor C. R. Moore spoke of the value of the books received by the members, and gave three prime reasons for membership; stimulus to better work, enthusiasm in work engendered, and helpfulness toward others. Mr. Witham and Mr. Potter also spoke briefly of the A.I.E.E. At the conclusion of the addresses, membership blanks were distributed. As a result, about 60 upper. classmen were enrolled as members of the Branch, and about 100 under classmen signed for membership in the local association.

New Branches

Two new Branches were authorized by the Institute Board of Directors at its meeting held on October 14, 1910. These Branches are as follows:

Throop Polytechnic Institute, Pasadena, Cal.

State University of Kentucky, Lexington, Ky.

This will bring the total number of Branches up to 32.

Personal

Mr. R. F. Trennert has changed his address from Pinchot, Cal., to Healdsburg, Cal., Box 556.

Mr. J. C. Preston announces a change of his address from Cos Cob, Conn., to Washington Inn, New Rochelle, N. Y.

Mr. J. E. Noeggerath has left the General Electric Company and opened an office as consulting engineer at 46 Wall Street, New York City.

Mr. John S. Van Horne, formerly with the U. S. Department of Commerce and Labor, has accepted a position with the Electrical Testing Laboratories of New York City.

Mr. J. McAllister Stevenson, Jr., fourth assistant examiner in the U. S. Patent Office, has changed his mailing address to 1808 I Street, N. W., Washington, D. C.

Mr. W. A. Schoel has left the Portland Railway, Light and Power Company to take charge of the steam plant and line department of the Northwestern Corporation, Dallas, Oregon.

Mr. P. H. Affolter, former manager of the Brush Light and Power Company of Brush, Colo., is now electrical salesman for Fairbanks, Morse and Company, San Francisco, Cal.

Mr. C. E. Ard, of Starkville, Miss., has been appointed professor of mechanical engineering and superintendent of construction at the Mississippi Agricultural and Mechanical College.

Mr. W. L. Upson has resigned from the electrical engineering department of the Ohio State University to become professor of electrical engineering at the University of Vermont.

Dr. Karl Georg Frank, representative of Siemens and Halske, and Siemens Schuckertwerke, has removed his offices to room 408, West Street Building, 90 West Street, New York City.

Mr. H. L. Lincoln recently resigned from the power and mining department of the General Electric Company, Schenectady, to enter the employ of the Commonwealth Edison Company, Chicago, Ill.

Mr. W. E. Nourse, who for the past six years has been with the Boston Edison Company, has accepted a position in the Boston office of the Cutler-Hammer Manufacturing Company, at 176 Federal Street.

Mr. Fernand F. Klenk, until recently in the test department of the New York Edison Company, has entered the electrical department of the Baltimore and Ohio Railroad Company at Baltimore, Md.

Mr. H. A. Dresbach, formerly operating engineer and electrician for the Van Dyck and Severn properties, has accepted a similar position with the Union Theological Seminary, Broadway and 120th Street, New York City.

Mr. Thomas R. Taltavall, for the last 14 years associate editor on the staff of the *Electrical World*, has resigned to take the editorship of the *Telegraph and Telephone Age*, of which he is part owner.

Mr. William Bradford has left the Lincoln Gas and Electric Light Company, Lincoln, Neb., of which he was general superintendent, and entered the electrical department of the Laclede Gas Light Company, of St. Louis, Mo.

Mr. R. T. Brooke, who for the last two years has been sales agent in the Atlanta office of the General Electric Company, was recently transferred to

Birmingham, Ala., as manager of the company's office in that city.

Mr. Joseph Mini, Jr., formerly in the general construction department of the Pacific Gas and Electric Company, San Francisco, has been appointed superintendent of the Colgate power division of the same company.

Mr. James Lynah, district purchasing agent for the E. I. du Pont de Nemours Powder Company, Wilmington, Del., has been made superintendent of the fabrikoid works of the same company at Newburgh, N. Y.

Mr. C. C. Webster, chief engineer of the city pumping station, Schenectady, N. Y., for the last six years, has resigned to become the proprietor and general manager of the La Veta Light, Heat and Power Company, La Veta, Colo.

Mr. J. C. Peet, instructor in electricity at Mechanics Institute, Rochester, N. Y., for the last three years, has taken charge of the department of electricity and physics at the new Technical High School, Harrisburg, Pa.

Mr. Irving E. Brooke has left the Arnold Company, of Chicago, and become associated with Mr. William H. Rosecrans in general consulting engineering work, with an office at 525 Chicago Stock Exchange Building, Chicago.

Mr. W. E. Chappell, formerly engineer for the Birmingham district of the British Westinghouse Electric and Manufacturing Company, Limited, has been appointed electrical engineer for the Staveley Coal and Iron Company Chesterfield, England.

Mr. F. T. Leilich has accepted the position of instructor in electrical engineering at the University of Pittsburg, Pittsburg, Pa. Mr. Leilich was formerly in the electrical department of the Baltimore and Ohio Railroad Company, Baltimore.

Mr. Fred R. Davis, chief engineer for the Charlotte Consolidated Construction Company, at Charlotte, N. C., has resigned to accept a similar position in the gas power plant of the Pittsburg Plate Glass Company, Crystal City, Mo.

Mr. Paul J. McCutcheon, until recently special alternating current representative of the Crocker-Wheeler Company at Ampere, N. J., has resigned and is now manager of the electrical department of the Pittsburg office of the H. W. Johns-Manville Company.

Mr. Volney Delos Cousins has entered the employ of the Pacific Telephone and Telegraph Company, in the plant engineering department, with headquarters in San Francisco, Cal. Mr. Cousins was an instructor in telephone engineering at Purdue University.

Mr. O. B. Wooten, instructor in physics in the Texas Agricultural and Mechanical College, has accepted a research fellowship in electrical engineering in the engineering experiment station at the University of Illinois, Urbana, Ill.

Mr. A. T. Appleton has resigned as electrical superintendent of the Canadian Portland Cement Company of Port Colborne to become chief electrician for the Oliver Chilled Plow Works of Canada. His address is 52 Locomotive Street, Hamilton, Ont.

Mr. R. M. Ostermann, formerly electrical engineer with Sussdorff, Zaldo and Company, agents for the General Electric Company in Havana, Cuba, has resigned and returned to his home in Berlin, Germany, where he hopes to restore his failing health.

MR. C. T. BOWRING has resigned from the New York erecting department of the Westinghouse Electric and Manufacturing Company, and is now acting as Canadian representative for several European manufacturing firms, with headquarters in Toronto, Ont.

MR. R. G. STEWART, for three years superintendent of the railway department of the Texarkana Gas and Electric Company, Texarkana, resigned on September 15 to engage in the automobile business at Memphis, Tenn., under the name of the Stewart Auto Company.

MR. FRANK J. CLARKE, who was equipment engineer for the Southern Bell Telephone and Telegraph Company, resigned recently to accept a position in the southern division of the American Telephone and Telegraph Company, with headquarters at Atlanta Ga.

MR. GEORGE J. JENISTA has been appointed professor of electrical engineering at the De Paul Engineering College, an institution recently organized in the northern part of Chicago. Mr. Jenista was formerly facility inspector with the Chicago Telephone Company.

MR. H. E. HEATH recently moved his offices to 1328 Broadway, New York City. Mr. Heath has had over 20 years' experience in the electrical field, with various large companies, and for some time has been engaged in consulting work, more recently in New York City.

MR. THEODORE STEBBINS, of Herrick and Stebbins, New York, has made a contract with the directors of the Springfield Light, Heat and Power Company, Springfield, Ohio, to manage its business. Mr. Stebbins has also accepted the management of the railway and lighting properties at Mt. Vernon, Ohio.

MR. B. C. DENNISON, Cornell 1904 and 1908, and instructor in electrical engineering at Cornell University, has left there to take charge of a course in electrical design and the theory of alternating-current machinery at the Carnegie Technical Schools of Pittsburg, Pa. His address is 1138 Murray Hill Avenue.

MR. PER FRENELL, consulting electrical engineer, has been appointed chief engineer of the Elektriska Profningsanstalten, in Gothenburg, Sweden. Mr. Frenell is an expert on high tension power transmission, and has been technical advisor for several of the largest installations of this character in Sweden.

MR. J. J. NIELSON, formerly chief draftsman with the Sanitary District of Chicago, in the electrical department, recently accepted the position of sales engineer for the States Electric Company, 24–30 South Clinton Street, Chicago, manufacturers of high and low tension switchboards, panel boards, and a general line of electrical specialties.

MR. HUGH A. BROWN has been appointed manager of the Chicago office of the Garwood Electric Company, 555 Old Colony Building. For the last two years Mr. Brown has been acting as sales manager for the Rockaway Coaster Company, of Cincinnati, Ohio, a company organized by his brother and himself, and from which Mr. Brown has now withdrawn.

MR. ARTHUR C. HOBBLE, who recently returned to the United States from Southern India, where he was employed as chief operator and hydraulic engineer of the generating plant of the Cauvery River Power Scheme, has entered the University of Illinois to take post-graduate work in electrical engineering. His address is 410 West High Street, Urbana, Ill.

MR. H. N. KEIFER, who is spending a few months in Montreal, will leave

there shortly for Vancouver, B. C., to take charge of all the telephone sales and engineering work for the Northern Electric and Manufacturing Company. Prior to accepting this position Mr. Keifer was employed by the Western Electric Company, in their engineering department at Chicago.

Mr. William M. Piatt, who for the last 11 years has been assistant engineer to J. L. Ludlow, at Winston-Salem, N. C., has become associated with Mr. Gilbert C. White, C. E., under the firm name of White and Piatt. The firm will do consulting work in civil, hydraulic and electrical engineering with headquarters at Durham, N. C., extending the practice already established there by Mr. White.

Library Accessions

The following accessions have been made to the Library of the Institute since the last acknowledgment.

Association of Railway Telegraph Superintendents. Proceedings of the Annual Meeting held at Los Angeles, Cal. June 20–22, 24, 1910. Milwaukee, n. d. (Gift of Association.)

Auckland City and Suburban Electric Tramways. Report of the Royal Commission Appointed to Inquire into the Efficiency of the Brakes, and Suitability of the Brake Systems, Adopted on the Auckland City and Suburban Electric Tramways. New Zealand, 1910. (Gift of Robt. J. Scott.)

Bemerkung zu Unserer Mitteilung: Das Magnetishce Spektrum und das Dopplerspektrum der Kanalstrahlen Von. E. Gehrcke und O. Reichenheim. (Sonderabdruck aus den Verhandlungen der Deutschen Physikalischen Gesellschaft. XII Jahrgang, no. 11.) Braunschweig, 1910. (Gift of Physikalisch-Technischen Reichsanstalt.)

Incorporated Gas Institute. Transactions 1891–1893. London, 1891–1893. (Purchase.)

Incorporated Institution of Gas Engineers. Transactions, 1897. London, 1898. (Purchase.)

Index of Papers and Subjects discussed by the Railway Clubs, from May 31, 1908 to May 31, 1909. N.p. n.d. (Gift of Society of Railway Club Secretaries.)

International Catalogue of Scientific literature 8th Annual Issue. C-Physics. London, 1910. (Gift of Adams Fund.)

Journal of Gas Lighting, Water Supply and Sanitary Improvements. Vol. 51–52, indexes; Vol. 59, nos. 1495–97, 1499, 1501, 1503–06, 1509, 1512, 1516; Vol. 60, nos. 1535, 1538; Vol. 80, no. 2057; Vol. 81, No. 2080; Vol. 83, No. 2103; Vol. 84, No. 2111; Vol. 90, index; Vol. 91, Nos. 2200–04, 2206; Vol. 92, Nos. 2222 and index; Vol. 93, Nos. 2229–30 and index. London, 1892, 1902–06. (Purchase.)

Das magnetische Spektrum und das Dopplerspektrum der Kanalstrahlen. Von E. Gehrcke und O. Reichenheim. (Sonderabruck aus den Verhandlungen der Deutschen Physikalischen Gesellschaft XII Jahrgang, No. 9.) Braunschweig, 1910. (Gift of Physikalische-Technischen Reichsanstalt.)

National Fire Protection Association. Rules and Requirements of the National Board of Fire Underwriters for the Construction and Installation of Gravity Tanks. 1910. Boston, 1910. (Exchange.)

——Rules and Requirements of the National Board of Fire Underwriters for the Construction, Installation and Use of Acetylene Gas Machines, and for the Storage of Calcium Carbide. 1910. Boston, 1910. (Exchange.)

——Rules and Requirements of the National Board of Fire Underwriters for the Construction, Installation and Use of Gasolene Vapor Gas Lighting Machines, Lamps and Systems. 1910. Boston, 1910. (Exchange.)

——Rules and Requirements of the National Board of Fire Underwriters for the Construction, Installation and Use of Oxy-Acetylene Heating and Welding Apparatus. 1910. Boston, 1910. (Exchange.)

——Rules and Requirements of the National Board of Fire Underwriters for the Construction of Valves, Indicator Posts and Hydrants for Mill Yard Use. 1910. Boston, 1910. (Exchange.)

——Rules and Requirements of the National Board of Fire Underwriters for Sprinkler Equipments Automatic and Open Systems. 1910. Boston, 1910. (Exchange.)

Official Guide of the Railways and Steam Navigation Lines of the United States, Porto Rico, Canada, Mexico and Cuba. October, 1910. (Donor unknown.)

Railway Library, 1909. By S. Thompson. Chicago, 1910. (Gift of author.)

Solenoids Electromagnets and Electromagnetic Windings. By C. R. Underhill. New York, D. Van Nostrand Co. 1910. (Gift of Publishers.) Price, $2.00 net.

Contents.—Chapter I.—Introductory. II.—Magnetism and Permanent Magnets. III.—Electric Circuit. IV.—Electromagnetic Calculations. V.—The Solenoid. VI.—Practical Solenoids. VII.—Iron-clad Solenoid. VIII.—Plunger Electromagnets. IX.—Electromagnets with External Armatures. X.—Electromagnetic Phenomena. XI.—Alternating Currents. XII.—Alternating Current Electromagnets. XIII.—Quick Acting Electromagnets and Methods of Reducing Sparking. XIV.—Materials, Bobbins and Terminals. XV.—Insulation of Coils. XVI.—Magnet Wire. XVII.—Insulated Wires. XVIII.—Electromagnetic Windings. XIX.—Forms of Windings and Special Types. XX.—Heating of Electromagnetic Windings. XXI.—Tables and Charts.

Strahlen der Positiven Elektrizität. By E. Gehrcke (Sonderabdruck aus Zeitschrift fur Elektrochemie N. p. n. d. (Gift of Physikalisch-Technischen Reichsanstalt.)

Throop Polytechnic Institute. Bulletin of Dedication Exercises, July, 1910. Pasadena, 1910. (Gift of H. S. Carhart.)

Trade Catalogues

Allgemeine Elektricitats Gesellschaft, Berlin. Enclosed installation apparatus, 18 pp.

——Territory of operation of various electric measuring and recording instruments, 22 pp.

Bryant and Perkins, Bridgeport, Conn. Wiring devices, switches, fuses, cut-outs, receptacles, etc., 120 pp.

Contractors Supply & Equipment Co., Denver, Colo. Catalogue of stock of new and second-hand contractor's machinery, tools, and supplies. 44 pp.

Cutler-Hammer Mfg. Co., Milwaukee, Wis. Battery charging rheostats. 48 pp.

Fort Wayne Electrical Works, Fort Wayne, Ind., Instruction Book No. 3043. Type K3 single-phase integrating induction watthour meters. 31 pp.

——Bull. No. 1121, "Northern" type B direct current generators. 4 pp.

——Bulletin No. 1124. Portable watthour meter calibrators, type KM-2 for alternating current. 4 pp.

——Bulletin No. 1125, Single-phase induction watthour meter, type K3. 7 pp.

General Electric Co., Schenectady, N. Y. National Electric Code Standard wires and cables, and lamp cords. 15 pp.

——Bulletin No. 4717. G. I. flame arc lamps. 16 pp.

——Bulletin No. 4739. The "Mazda" incandescent lamp for standard lighting service. 23 pp.

——Bulletin No. 4743. Intensified arc lamps for store lighting. 15 pp.

——Bulletin No. 4744. Meter testing rheostats for 110–120 volts. 2 pp.

General Electric Co., Schenectady, N.Y. National Electric code standard red core; tricoat; and 30 per cent para wires, cables, and lamp cords. 20 pp.

—Bull. No. 4749—Alternating current switchboard panels, three phase, three-wire, and single phase 1150 and 2300 volts, 25/125 cycles. 69 pp.

—Bull. No. 4755—Electrification of the Cascade Tunnel of the Great Northern Railway Co. 15 pp.

—Bull. No. 4763—Isolated plant-direct current combination generator and feeder cables. 6 pp.

—Bull. No. 4767—Large motors for steel mills. 15 pp.

National Pneumatic Co., Chicago, Ill. Devices and appliances for operation and control of doors, gates, windows of street and railway cars. 12 pp.

—Pneumatic operating device for sliding the doors of the "Pay-Within" cars. 13 pp.

Pettingell-Andrews Co., Boston, Mass. Juice, October, 1910, published in the interest of electric lighting and power. 16 pp.

Sprague Electric Co., New York City. Flexible steel armored hose. 12 pp

—Alternating current electric fans. 20 pp.

—Bulletin No. 600. Single and polyphase induction motors. 39 pp.

Underwriters National Electric Association New York. April 1910 list of electrical fittings for installation of electric wiring and apparatus, required by the National Board of Fire Underwriters. 98 pp.

Walker Electric Co., Philadelphia, Pa. Switchboards for power and light. 213 pp.

Western Electric Co., Hawthorn, N. Y. Bulletin No. 1008. Telephones power plant equipments for non-multiple switchboards. 23 pp.

Westinghouse Elec. & Mfg. Co., Pittsburg, Pa. Additional addenda and material for the permanent electrical catalogue. 100 sheets.

United Engineering Society

American Trade Index. (Domestic Edition.) 1908–1910. New York, 1910. (Gift of National Association of Manufacturers.)

Breakdown Connections to Isolated Plants. By M. F. McAlpin. New York, 1910. (Gift of author.)

Deutscher Verein von "Gas und Wasserfachmännern. Verhandlungen. 1891–1901. Munchen, 1892–1902. (Purchase.)

Poor's Manual of Railroads, 1910. New York, 1910. (Purchase.)

Engineering Record. Vol. 24, New York, 1891. (Exchange.)

Kansas, Gas, Water, Electric Light & Street Railway Association. 12th Annual Meeting, Wichita, Kan., Sept. 23–24, 1909. n.p. n.d. (Gift of Association.)

Michigan Gas Association. Proceedings of the 18th Annual Meeting, 1909. (Gift of Association.)

Statement of "Facts" Concerning the so-called "Barcroft Appraisal" of the Detroit United Railway Lines in the City of Detroit, Aug. 1910. (Gift of R. B. Rifenberick.)

OFFICERS AND BOARD OF DIRECTORS, 1910-1911.

PRESIDENT.

(Term expires July 31, 1911.)

DUGALD C. JACKSON.

JUNIOR PAST-PRESIDENTS.

LOUIS A. FERGUSON. LEWIS B. STILLWELL.

VICE-PRESIDENTS.

(Term expires July 31, 1911.)	(Term expires July 31, 1912.)
JOHN J. CARTY.	MORGAN BROOKS.
PAUL M. LINCOLN.	HAROLD W. BUCK.
PAUL SPENCER.	PERCY H. THOMAS.

MANAGERS.

(Term expires July 31, 1911.)	(Term expires July 31, 1912.)	(Term expires July 31, 1913.)
DAVID B. RUSHMORE.	A. W. BERRESFORD.	H. H. BARNES, JR.
W. G. CARLTON.	WILLIAM S. MURRAY.	C. E. SCRIBNER.
CHARLES W. STONE.	HENRY H. NORRIS.	W. S. RUGG.
H. E. CLIFFORD.	SEVERN D. SPRONG.	R. G. BLACK.

TREASURER. (Term expires July 31, 1911.) **SECRETARY.**

GEORGE A. HAMILTON. RALPH W. POPE.

NOTE:—The Institute Constitution provides that the above named twenty-three officers shall constitute the Board of Directors.

PAST-PRESIDENTS.—1884-1909.

*NORVIN GREEN, 1884-5-6.
*FRANKLIN L. POPE, 1886-7.
T. COMMERFORD MARTIN, 1887-8.
EDWARD WESTON, 1888-9.
ELIHU THOMSON, 1889-90.
*WILLIAM A. ANTHONY, 1890-91.
ALEXANDER GRAHAM BELL, 1891-2.
FRANK J. SPRAGUE, 1892-3.
EDWIN J. HOUSTON, 1893-4-5.
LOUIS DUNCAN, 1895-6-7.
FRANCIS B. CROCKER, 1897-8.
A. E. KENNELLY, 1898-1900.
CARL HERING, 1900-1.
CHARLES P. STEINMETZ, 1901-2.
CHARLES F. SCOTT, 1902-3.
BION J. ARNOLD, 1903-4.
JOHN W. LIEB, JR., 1904-5.
SCHUYLER S. WHEELER, 1905-6.
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Worcester Poly. Inst .. Mar.	25, '04	W. C. Greenough.	H. E. Hartwell, Worcester Poly. Inst., Worcester, Mass.

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PROCEEDINGS

OF THE

American Institute

OF

Electrical Engineers.

Published monthly at 33 W 39th St., New York, under the supervision of

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Vol. XXIX **December, 1910** No. 12

December Meeting of A.I.E.E.

The two hundred and fifty-fourth meeting of the American Institute of Electrical Engineers will be held in the auditorium of the Engineers' Building, 33 West 39th Street, New York City, on Friday evening, December 9, 1910, at 8:15 p.m. A paper entitled "Testing Steam Turbines and Steam Turbo-Generators," will be presented by Messrs. E. D. Dickinson and L. T. Robinson, both of the General Electric Company. The paper is printed in this issue of the PROCEEDINGS.

Meeting of A.I.E.E. in New York, January 13, 1911

The January meeting of the Institute will be held in the Engineers' Building, 33 West 39th Street, New York City, on Friday, January 13, 1911. This meeting is to be under the auspices of the High Tension Transmission Committee, and the subject, "Corona," will be treated by Professor Harris J. Ryan, of Stanford University, California. Further details will be announced in the January PROCEEDINGS.

Pittsfield-Schenectady Mid-year Convention

The date of the proposed Pittsfield-Schenectady Mid-Year Convention has not as yet definitely been determined upon, but it is understood that it will be held early in February 1911. As already announced this convention will be of the same character as the meetings at Charlotte and San Francisco last spring. Two of the papers which will be presented are printed in this issue of the PROCEEDINGS. These papers are, "Problems in Operation of Transformers," by F. C. Green, and Mechanical Forces in Magnetic Fields," by Dr. C. P. Steinmetz. The balance of the papers will appear in the January and February PROCEEDINGS. President Jackson has appointed the following local committee, which will take charge of the arrangements:

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L. T. Robinson, Schenectady.

G. Faccioli, Pittsfield, Mass.

C. W. Stone, Schenectady, N. Y.

Further details will be published from time to time as the plans of the committee mature.

Educational Meeting December 8, 1910

A meeting will be held in the auditorium of the Engineers' Building, New York City, December 8, 1910, by the National Society for the Promotion of Industrial Education, with the coöperation of the American Institute of Electrical Engineers, the American Society of Mechanical Engineers and the American Institute of Mining Engineers. The subject of the evening will be "Industrial Continuation Schools of Munich," by Dr. Georg Kerschensteiner, Superintendent of Schools, Munich, Bavaria. Dr. Kerschensteiner has been for many years at the head of

the progressive movement in Germany for more practical industrial education, and is responsible for the development of the part-time schools in Munich that are attended by all apprentices and other boys and girls at work between 14 and 18 years of age. The keynote of Dr. Kerschensteiner's theory of industrial education is coöperation between the employer and the public school system. This is the basis upon which is founded the successful system of schools for every important industry in Munich. The address will be illustrated by lantern views of the Munich schools and classes.

Future Section Meetings

MILWAUKEE

The next meeting of the Milwaukee Section will be held in coöperation with the Engineers' Society of Milwaukee in the colonial room of the Plankinton House, Milwaukee, Wis., on December 14, 1910, at 8:15 p.m. Mr. A. G. Hendrichs, of the American Oxhydric Company, will give a talk and demonstration on the "Cutting of Metals by the Oxhydric Process."

PORTLAND, OREGON

The Portland Section will hold its next meeting in the assembly hall of the Electric Building, Portland, Oregon, on December 13, 1910. The speaker will be Mr. W. H. Evans, of the Southern Pacific Company, who will address the members on a railway subject.

Future meetings thus far arranged are as follows:

January 17, 1911—Subject, *Conservation of Natural Resources*, by E. J. Griffith.

February 21, 1911—Subject, *Telegraph and Telephone Work*, by E. L. Ritter, of the Pacific Telephone and Telegraph Company.

WASHINGTON, D. C.

The Washington Section will hold its regular meeting on December 13, 1910, in the Telephone Building, at 8:00 p.m. Mr. A. H. Lawton, assistant chief electrical engineer of the New York Edison Company, will present a paper on "The Electrical Development of the New York Edison Company."

Institute Meeting at New York November 11, 1910

The two hundred and fifty-third meeting of the American Institute of Electrical Engineers was held in the auditorium of the Engineers' Building, 33 West 39th Street, New York City, on Friday evening, November 11, 1910. President Dugald C. Jackson presided, and called the meeting to order at 8:15 p.m. The Secretary announced that at the meeting of the Board of Directors held during the afternoon 42 Associates were elected, and six Associates were transferred to the grade of Member. The names of the Associates elected and those transferred are printed elsewhere in this issue. A paper on "Interpoles in Synchronous Converters," by Messrs. B. G. Lamme and F. D. Newbury was read in abstract by Mr. Newbury. The paper was discussed by Messrs. Gano Dunn, H. F. T. Urban, C. P. Steinmetz, Jens Bache-Wiig, P. M. Lincoln, J. L. Burnham, C. W. Stone, C. A. Adams, and Elihu Thomson.

Directors' Meeting, November 11, 1910

The regular monthly meeting of the Institute Board of Directors was held at 33 West 39th Street, New York City, on Friday, November 11, 1910. The directors present were: President Dugald C. Jackson, Boston, Mass.; Vice-Presidents, P. M. Lincoln, Pittsburg, Pa., Morgan Brooks, Urbana, Ill., Percy H. Thomas, New York; Managers, W. G. Carlton, New York, Charles W. Stone, Schenectady, N. Y., A. W. Berresford, Milwaukee, Wis., W. S. Murray, New Haven, Conn., H. H. Norris, Ithaca, N. Y., S. D. Sprong, New York, H. H. Barnes, Jr., New York; Treasurer, George A.

Hamilton, Elizabeth, N. J.; Secretary Ralph W. Pope, New York.

Forty-two candidates for membership in the Institute as Associates were elected.

One hundred and four Students were declared enrolled.

Six Associates were transferred to the grade of Member, as follows:

JOSEPH HAROLD LIBBEY, Mechanical and Electrical Engineer, Stone and Webster Engineering Corporation, Boston, Mass.

LEWIS LITTLEPAGE HOLLADAY, Associate Professor of Electrical Engineering, University of Virginia, Charlottesville, Va.

WILLIAM NELSON MOTTER, Electrical Engineer, Allis-Chalmers Company, Milwaukee, Wis.

CLARK T. HENDERSON, Electrical Engineer, Cutler-Hammer Mfg. Company, Milwaukee, Wis.

CLARENCE E. DOOLITTLE, Consulting Hydraulic and Electrical Engineer and V. P. and Gen. Mgr., Roaring Fork Electric Light and Power Company, Aspen, Colo.

OLIN JEROME FERGUSON, Assistant Professor of Electrical Engineering, Union College, Schenectady, N. Y.

Associates Elected November 11, 1910

ALLISON, LEROY WARD, Draftsman, Pacific Light & Power Co.; res., 1353 West 30th St., Los Angeles, Cal.

BERKELEY, LANDON ROBINSON, National Carbon Co., Publicity Division, Cleveland, Ohio.

BOYD, WILLIAM BEVERLEY, Chief Electrical Engineer, Toronto Railway Company, Toronto, Ontario.

BROWN, RICHARD PERCY, President, Brown Instrument Co., 311 Walnut St., Philadelphia, Pa.

CHARLES, WALTER, Inspector, Detroit River Tunnel Co., M. C. Depot; res., 141 Warren Ave., Detroit, Michigan.

CHRISTENSON, OSCAR, Superintendent, Marconi Wireless Telegraph Station, South Wellfleet, Mass.

COBB, RALPH MONROE, Construction Foreman, Line Department, Pacific Electric Ry.; res., 438 So. Olive St., Los Angeles, Cal.

DIERCK, RICHARD E. F., Director, Siemens-Schuckertwerke fur die La Plata Staaten, Casilla de Correo 1081, Buenos Aires, A. R.

FAIRLY, GUY ERNEST, Electrician, Los Angeles Aqueduct, Sauqus, Cal.

GAIN, LOUIS D'ORIVAL ALFRED, Electrical Designer & Draughtsman, Western Canada Power Co., 198 Hastings St., Vancouver, B. C.

GOODELL, WILLIAM SANFORD, Foreman of Construction, Sprague Electric Co., Fisher Building, Chicago, Ill.

GOUTY, MERLE B., Electrical Engineer, Ft. Wayne & Wabash Valley Traction Co., Ft. Wayne, Ind.

GUNNING, JOHN FREDERICK, Electrical Engineer, Empire Vacuum Co., 112 West 30th St.; res., 4578 Park Ave., New York City.

HOYT, FRANK WATSON, Mechanical Engineer, Fort Wayne Electric Works, Fort Wayne, Indiana.

JENKINS, MICHAEL OSWALD, Power Engineer, New York Edison Co., 55 Duane St., New York City.

JERAULD, RODMAN ERNEST, Commercial Engineer, General Electric Co., Newhouse Bldg., Salt Lake City, Utah.

JOHNSON, CHARLES BAKER, Construction Foreman, General Electric Co.; res., 240 Noe St., San Francisco, Cal.

JONES, JULIAN DOUGLAS, Electrical Engineer, Broad St., Station, Penna. R.R. Co., res., 5241 Walnut St., Philadelphia, Pa.

LANCASTER, JOHN GILL, Engineer, Erecting Dept., Westinghouse Electric & Mfg. Co., 510 W. 23rd St.; res., 27 West 125th St., New York City.

LOSEY, GEORGE HOLMAN, Electrical Engineer, Kokomo, Marion & Western Traction Co., Kokomo, Indiana.

MARSHALL, VERNON RAY, Station Superintendent, Dillon Sub-station, Central Colorado Power Co., Dillon, Colo.

McManus, Edward Francis, Electrical Engineer, 216 Market St.; res., 2816 Center Ave., Pittsburg, Pa.

Monahan, John Gerald, Travelling Representative, Ferranti Ltd., 1688 Dundas St., Toronto, Ont.

Mooney, Frank P., Arrowhead Reservoir & Power Co., San Bernardino, Cal.

Newcomb, Laurence Lyle, Electrical Operator, Nevada-California Power Co., Bishop, Cal.

Newton, George Johnson, with G. M. Gest, 277 Broadway, New York City.; res., 66 Johnson St., Brooklyn, N. Y.

Nicht, Alexander J., Jr., Electrical Engineer, Allis-Chalmers Co.; res., 532 38th St., Milwaukee, Wis.

Norsa, Renzo, Electrical Engineer, New York Edison Co., 55 Duane St.; res., 30 East 22nd St., New York City.

North, Felix Stanley, Secretary, Treasurer & General Manager, Suffolk Gas & Electric Light Co., Bay Shore, L. I., N. Y.

Nussbaum, Victor M., Salesman, Fort Wayne Electric Works; res., 1817 Spy Run Avenue, Fort Wayne, Ind.

Osborne, Harold Smith, Assistant, Engineering Department, American Tel. & Tel. Co., 15 Dey St., New York City.

Paul, Charles A., Manager, United Illuminating Co.; res., 965 Fairfield Ave., Bridgeport, Conn.

Pridham, Edwin Stewart, Engineer, Poulsen Wireless Telephone and Telegraph Co., Stanford University, Cal.

Ritter, Hans Karl, Electrical Engineer, Brown, Boveri & Co., res., 454 Zurcherstrasse, Baden Switzerland.

Sano, Shiro, Professor of Electrical Engineering, College of Engineering, Waseda University, Tokio, Japan.

Schaaf, Daniel Louis, Chief Operator, Bay Shore Sub-station, Sierra and San Francisco Power Co.; res., 4418 San Bruno Ave., San Francisco, Cal.

Schreiber, Karl Edward, Erecting Engineer, Westinghouse Electric & Mfg. Co., Kansas City, Mo.

Silvernail, Frank D., Chief Electrical Engineer, Lockport Water Supply, North Tonawanda; res., 186 Church St., Lockport, N. Y.

Spencer, Robert Howard, Constructing Electrician, Southern California Edison Co., Los Angeles, Cal.

Stearns, Ralph W., Designing Engineer, General Electric Co.; res., 306 Crane St., Schenectady, N. Y.

Temple, Herbert Asher, Electrical Draftsman, Public Service Commission, Tribune Bldg.; res., 419 West 118th St., New York City.

Turner, Edgar Percival, Engineer in Charge Power Station, Christchurch Tramway Board, Christchurch, New Zealand.

Applications for Election

Applications have been received by the secretary from the following candidates for election to the Institute as Associates; these applications will be considered by the Board of Directors at a future meeting. Any Member or Associate objecting to the election of any of these candidates should so inform the secretary before December 24, 1910.

9790 Naugle, P. D., Bremerton, Wash.
9791 Sheen, H. L., Toronto, Ont.
9792 Zachau, C. E. K., Muskegon, Mich
9793 Douglas, J. F. H., Ithaca, N. Y.
9794 Howell, C. H., Pittsburg, Pa.
9795 Moore, W. A., Schenectady, N. Y.
9796 Smith, W. P., Corozal, C. Z.
9797 Gaylord, J. C., Los Angeles, Cal.
9798 Josephs, L. C., Jr., New York City
9799 Perry, C. C., New Haven, Conn.
9800 Rutherford, H. K., Durango, Mex.
9801 Seabright, H. A., Boise, Idaho.
9802 Towers, A. C., Ithaca, N. Y.
9803 Gates, A. B., Alhambra, Cal.
9804 Nichols, H. L., Chicago, Ill.
9805 Scott, H. G., Shelby, Ohio.
9806 Zanzig, F. C., Worcester, Mass.
9807 Moreton, D. P., Chicago, Ill.
9808 Coffey, W. J., New York City.
9809 Hammond, H. B., New York City.
9810 Hunt, L. J., Sandycroft, England.
9811 Hutchinson, G. E., East Orange, N.J.

9812 Jacobson, A. F., New York City.
9813 Jacobson, J. H., Chicago, Ill.
9814 Morkill, R. F., New York City.
9815 Neville, W. J., Chicago, Ill.
9816 Nightingale, R., Bremerton, Wash
9817 Quick, R. L., Ithaca, N. Y.
9818 Keplinger, W. L., Newton, N. J.
9819 Sprung, A., New York City.
9820 Tanz, I., New York City.
9821 Thatcher, W. C., Chicago, Ill.
9822 West, E. A. G., Portland, Ore.
9823 Bruderlin, F., Denver, Colo.
9824 Gee, P. M., Schenectady, N. Y.
9825 Harvey, H. G., New York City.
9826 Hedges, G. L., Los Angeles, Cal.
9827 Jagger, C. A., Schenectady, N. Y.
9828 Lewis, F. H., Hagerstown, Md.
9829 Mott, H. W., New York City.
9830 Stewart, G. E., New York City.
9831 Faucett, Irving, Brooklyn, N. Y.
9832 Hardenbergh, J. R., N. Y. City.
9833 Work, N. R., Columbus, Ohio.
9834 Champion, R. B., Holland, Mich.
9835 Mead, D. W., Madison, Wis.
9836 Morss, E., Boston, Mass.
9837 Richards, K., Chicago, Ill.
9838 Vail, G. S., Cleveland, Ohio.
9839 Warren, F. S., Napa, Cal.
9840 Peters, O. S., Washington, D. C.
9841 Davis, W. De O., Topeka, Kansas.
9842 Ryan, A. T., Schenectady, N. Y.
9843 Taber, R. H., Worcester, Mass.
9844 Williams, F. S., Roanoke, Va.
9845 Bergen, T. A., Boston, Mass.
9846 Denhard, H. W., Milwaukee, Wis.
9847 Ellicott, E. B., Chicago, Ill.
9848 Firth, H. W., London, England.
9849 Greenwood, W. K., Orilla, Ont.
9850 Henderson, C. L., Knoxville, Tenn.
9851 Huntington, R. C., New Haven, Conn.
9852 MacMurray, O., East Orange, N.J.
9853 Nute, E. L., Vernon, Vt.
9854 Ridgely, H. P., Milwaukee, Wis.
9855 Westbrook, L., Dallas, Texas.
9856 Davis, R. W., Milwaukee, Wis.
9857 Lucas, S. M., Pittsburg, Pa.
9858 Lott, M. R., Provo, Utah.
9859 Percival, J. T., Jr., Spokane, Wash.
9860 Code, E. S., Seattle, Wash.
9861 Fiske, G., Chicago, Ill.
9862 Norton, P., New York City.
9863 Sherwood, W. R., Brooklyn, N. Y.
9864 Stadeker, G. I., New York City.
9865 Schrodt, J. P., Newark, N. J.
9866 Lutes, E., New York City.
9867 Murphy, H. E., Milwaukee, Wis.
9868 Van Kuran, Karl, Pittsburg, Pa.
9869 Weeks, H. E., Mt. Vernon, N. Y.
9870 Cobb, P. L., New York City.
9871 Berg-Hansen, B., Hardanger, Norway.
9872 Zachrisson, S. G. E., Schenectady, N. Y.
9873 Bauhan, A. E., Jersey City, N. J.
9874 McElyea, H. B., Chicago, Ill.
9875 Wilkerson, S. C., Jr., Fayettville Ark.
9876 Roush, L. W., Gunnison, Utah.
9877 Easton, C. L., North Fork, Cal.
9878 Flashman, H. W., New York City.
9879 Kroener, G. A., New York City.
9880 Mano, Bunji, Tokyo, Japan.
9881 Mayor, W. A., Lynn, Mass.
9882 Page, Roy, Berkeley, Cal.
9883 Shekell, F. L., Charleston, W. Va.
9884 Shippee, W. P., Spanish Fork, Utah.
9885 Wallower, E. Z., Harrisburg, Pa.
9886 Anderson, L. H., Guayaquil, Ecuador.
9887 Barnes, W. S., Kansas City, Mo.
9888 Gomo, B. L., Fon du Lac, Minn.
9889 Hatfield, H. B., San Francisco, Cal.
9890 Morphy, B. H., London, S.W., Eng.
9891 Morss, H. A., Boston, Mass.
9892 Phillip, H. J., Ames, Colo.
9893 Robbins, T. W., Aspen, Colo.
9894 Robinson, C.A., Jr., NewYorkCity.
9895 Runchey, J. A., Spokane, Wash.
9896 Strait, E. N., Madison, Wis.

Total 107.

Students Enrolled November 11, 1910

3861 Cockburn, L. S., Univ. of Toronto.
3862 Haynes, P. C., Univ. of Mich.
3863 Merriman, H. O., Univ. of Toronto
3864 Fletcher, J. H., Armour Inst. Tech.
3865 Pearson, G. A., Univ. of Penna.
3866 Sara, R. A., Univ. of Toronto.
3867 Sheadel, J. B., Purdue University.
3868 Miles, C. T., Purdue University.
3869 May, W. M., Purdue University.
3870 Adams, Quinton, Purdue Univ.
3871 Freeman, M. T., Purdue Univ.
3872 Phillips, C. E., Purdue Univ.

3873 Garn, P. A., Purdue University.
3874 Hall, Nelson, Purdue Univ.
3875 Fitzpatrick, W. L., Purdue Univ.
3876 Robinson, P. W., Purdue Univ.
3877 Adams, F. A., Cornell Univ.
3878 Coggeshall, C. S., Cornell Univ.
3879 Coler, C. S., Cornell University.
3880 Dix, H. W., Cornell University.
3881 Frost, H. M., Cornell Univ.
3882 Gailey, Austen, Cornell Univ.
3883 Giles, G. S., Cornell Univ.
3884 Goetz, W. W., Cornell Univ.
3885 E. MacNaughton, Cornell Univ.
3886 Platt, H. M., Cornell, Univ.
3887 Whitty, J. J., Cornell Univ.
3888 Wing, R. N., Cornell Univ.
3889 Lawson, R. A., Cornell Univ.
3890 Parker, R. I., Univ. of Kansas.
3891 Christensen, C. P., Stanford Univ.
3892 Bird, C. A., Univ. of Michigan.
3893 Vanderfield, E. W., Univ. of Mich.
3894 Snow, H. A., Univ. of Mich.
3895 Bauer, O. W., Univ. of Mich.
3896 Walker, A. S., Univ. of Mich.
3897 Nord, J. W., Univ. of Michigan.
3898 Stover, D. A., Univ. of Arkansas.
3899 Hertzog, H. S. Columbia Univ.
3900 Rothwell, H. D., Univ. of Toronto.
3901 Hoddinott, R. J., Case School Science.
3902 Munch, A. H., Univ. of Illinois.
3903 Gordon, Chas., Univ. of Illinois.
3904 Harvey, E., Purdue University.
3905 Beach, E. J., Purdue University.
3906 Sturm, A. F., Purdue Univ.
3907 Burwell, H. W., Purdue Univ.
3908 Hague, A. E., Purdue Univ.
3909 Fisher, D. L., Purdue Univ.
3910 Williams, F. G., Purdue Univ.
3911 Mayfield, F. A., Purdue Univ.
3912 Keller, L. M., Univ. of Michigan.
3913 Shaw, C. F., Univ. of Michigan.
3914 Linsday, A. C., Univ. of Michigan.
3915 Lobban, J. H., Univ. of Michigan.
3916 Kuehne, J. H., Armour Institute.
3917 Johnston, D. A., Yale Univ.
3918 Huston, F. P., Univ. of Missouri.
3919 Rooker, J. F., Univ. of Missouri.
3920 Helmreich, L. W., Univ. of Mo.
3921 Lee, C. K., Univ. of Missouri.
3922 Halstead, J. M., Univ. of Missouri.
3923 Read, W. G., Univ. of Missouri.
3924 Guengerich, E. J., Univ. of Mo.
3925 McDonald, E. C., Univ. of Mo.
3926 Lankford, C. H., Univ. of Mo.
3927 Smith, E. G., Harvard Univ.
3928 Post, J. H., Ohio State Univ.
3929 Keebler, H. M., Penn State Coll.
3930 Edel, A. F., Cornell University.
3931 Hadley, H. D., Cornell Univ.
3932 Slocum, L. M., Jr., Cornell Univ.
3933 King, R. P., Cornell Univ.
3934 Frank, C. F., Cornell Univ.
3935 Girvin, C. W., Cornell Univ.
3936 Gaillard, D. S. P., Mass.Inst.Tech.
3937 Mathers, H. L., Penn State Coll.
3938 Kintzing, R. T., Penn. State Coll.
3939 Thomas, L. H., Univ. of Michigan.
3940 Darrow, W. E., Univ. of Mich.
3941 Brelsford, H. E., Univ. of Mich.
3942 Rennie, W. M., Univ. of Mich.
3943 Kantorwitz, H., Washington Univ.
3944 Postel, P. H., Jr., Wash. Univ.
3945 Baldwin, L. A., Univ. of Kansas.
3946 Tuck, D. H., Mass. Inst. Tech.
3947 Blumhard, H. L., Swarthmore Coll.
3948 Abrahamson, O. F., Armour Inst.
3949 Lohse, A. C., Armour Institute.
3950 Harbecke, H. H., Kansas State Agr. Coll.
3951 Bernard, G., Kans. State Agr. Coll.
3952 Hillebrandt, B. F., Kansas State Agr. Coll.
3953 Detwiler, V. V., Kansas State Agr. Coll.
3954 Reed, E. C., Kansas State Agr. Coll.
3955 Roth, D. G., Kans. State Agr. Coll.
3956 Shaw, C. L., Kans. State Agr. Coll.
3957 Reynolds, R. H., Kansas State Agr. Coll.
3958 Lempke, W. J., Univ. of Neb.
3959 Wolesensky, F., Univ. of Neb.
3960 Westerfield, S. Z., Univ. of Neb.
3961 Hornung, F. W., Univ. of Neb.
3962 Randall, H. E., Univ. of Iowa.
3963 Aaron, J. A., Mass. Inst. Tech.
3964 Mac Murchy, H. G., Univ. of Toronto.

Total, 104.

The Development of the Moore Vacuum Tube Light*

The subject of light is worthy of exhaustive study. The goal of illuminating engineers is light without heat, or light by luminescence. The common candle was in its time a very useful invention. As the development of light proceeded, various forms of lighting appeared. The advent of the Geissler tube, which in its simplest form is a sealed glass tube with air exhausted to a low point, opened a new field to the electrical engineer. This was followed by the Crookes tube, similar in principle to the Geissler tube, but having a higher degree of vacuum. This led to the discovery of the X-ray. It was in 1891 that the writer, noting a statement that 99.7 per cent of the energy of coal used in producing light is lost, thus only three-tenths per cent of one per cent being utilized, resolved to bend his energies in the direction of developing a more efficient light. The result of his efforts has been the development of a new form of light which has been brought to a high state of perfection. Those who have visited the large stores and public buildings of any of our larger cities have seen the Moore vacuum tube light in actual operation. As usually installed it consists of a long glass tube strung on the ceiling, and giving off a brilliant but soft light. There are two standard qualities of the Moore light; yellow and white. The yellow used for general illumination, employs nitrogen vapor in the tubes. The white, which produces a light exactly similar to the light of day, employs carbon dioxide as a vapor. The white light is the only light by which color values properly can be judged. Its greatest use is in lighting such places as department stores, dye factories, silk mills, etc., where colors are handled. The efficiency of the yellow Moore light is higher than that of any other form of light; that is, it uses less energy for the same effective illumination than any other form of light. Probably the most ingenious feature of the Moore light is the valve which automatically supplies the proper amount of vapor to the tube in order to keep the vacuum within the proper range. A plunger, operated by the change in current value, displaces a varying amount of mercury in a tube leading into the Moore tube proper. The mercury normally covers a carbon plug, thus sealing the tube, but with an increase in current the plunger rises, displacing less mercury and uncovering the carbon plug, through which the mercury percolates, thus lowering the vacuum again to the proper point.

* Abstract of an address before the Pittsfield Section of the American Institute of Electrical Engineers on November 10, 1910.

The Chemistry of Mineral Oils*

BY A. MCK. GIFFORD

For the insulation of electrical devices designed for operation at temperatures under 100 degrees centigrade, there is no more important class of materials than the complex mixtures of hydrogen and carbon known as the bitumens. They might be classified as follows:

Gaseous..................	Natural gas
Liquid....................	Petroleum
Semi solid................	Maltha
Solid.....................	Asphalt

Petroleum is derived from natural gas, and the semi solids and solids are derived from petroleum by means of continued evaporation, and possibly due to a breaking up of the hydrocarbon molecules due to heat and pressure. All of these products are dielectrics or electrical insulators, and consequently are of great interest to electrical engineers. The asphalt, in combination with rosin and linseed oil is used in filling the interstices of wire wound coils in transformers and generators. The semi solids together with asphalt find application as the base for various black insulating varnishes and japans. Probably the most useful and interesting of all these bodies, however, is the liquid petroleum, from which come the oils

* Abstract of a paper presented before the Pittsfield Section of the American Institute of Electrical Engineers on November 9, 1910.

used in the electrical and other trades. There are two theories as to the origin of mineral hydrocarbons. Some scientists believe in their inorganic origin, and others assume that petroleum is the product of the decomposition of organic matter. The first theory assumes that at the beginning of things, when cooling of the original molten mass of the earth commenced, a condensation of vast clouds of vaporized water took place towards the molten center, these supplying the conditions necessary to formation of hydrocarbons; namely, high temperature and tremendous pressure, causing the hydrogen of the water to combine with the carbon of the carbide, and the oxygen to combine with the iron. The second theory, supported by most American geologists, holds that hydrocarbons of this nature are derived from both animal and vegetable sources, by being subjected to the right pressures and temperatures. Products rich in nitrogen may be traced to the decomposition of animal fats, while those free from nitrogen are probably derived from the disassociation of prehistoric wood and vegetable fibre. A table presenting a general idea of the ultimate composition of American petroleum is as follows:

	Hydrogen	Carbon	Nitrogen
Ohio........	13.07%	86.31%	0.23%
West Virginia	13.36%	85.20%	0.54%
California....	11.82%	86.93%	1.11%

Sulphur in crude petroleum averages 0.5 per cent. This sulphur is always in combination with the hydrocarbons. Sulphides of hydrocarbons will not react with copper. Free sulphur, however, readily attacks copper, forming a conducting salt known as cuprous sulphide. Oil from American fields comes from strata of varying depths, the shafts of the different wells ranging from 60 to 1,200 feet in depth. Access to the oil bearing sands is had by means of drills, and sometimes by use of nitro-glycerine. Practically all petroleum from the oil fields is transported by pipe-lines to the refineries and shipping points on the sea-coast. By filtration through charcoal, many of the viscous oils may be used without further treatment. These oils are known as "natural oils". The better grades of lubricating oils are distilled by the vacuum process at very low temperatures and sold as reduced oils. Most of the commercial illuminating and lubricating oils are produced from crude oil by fractional distillation. The average American still is about 30 feet long by 12 feet in diameter and holds about 600 gallons.

The so-called "cracking" process revolutionized the mineral oil industry, since by its use the burning oil output was increased from 50 per cent to 80 per cent. This method was discovered accidentally in 1861 in Newark, New Jersey. A still had been left over a very hot fire longer than planned, and it was found that a light colored distillate of lower density had been collected. This led to many experiments, with the result of increased production, as stated above. For insulation of oil-immersed electrical apparatus, it is desirable to have as light an oil as possible, in order more readily to carry away the heat. The lighter oils have; however, low flash and burning points, so that great care has to be used in the selection of oil for given conditions. Water is the greatest enemy of oil for insulating purposes, even 1/10 of one per cent reducing the dielectric strength one half. Although many methods have been proposed for the removal of water from oil, probably the best, and at the same time the simplest and cheapest, is that using ordinary filter paper.

Transformer Installations*

BY M. H. COLLBOHM

Transformer installations may be classed under the following heads: (*a*) Choice of transformers with regard to size and construction; (*b*) Location of transformers with regard to accessi-

* Abstract of a paper presented before the Madison Section of the American Institute of Electrical Engineers on November 9, 1910.

bility and fire hazard; (*c*) Methods of Cooling; (*d*) Testing of oil and treating of deteriorated oil; (*e*) Choice of connections for high pressure windings, whether star or delta. In making a choice of transformers for plants up to 5,000 or 6,000 kw. capacity having only one transmission line, two banks of transformers connected in parallel, each bank comprising three single-phase units, and one extra single-phase unit for use in cases of emergency, are preferable. For larger stations, and especially those supplying several independent transmission lines, preference should be given to the three-phase type of transformer on account of its space economy.

In placing transformers each unit should be put in a separate fire-proof compartment, as nearly air-tight as possible. The compartments should be located so that the transformers may be rolled out to positions where they may be handled readily by the power-house crane. Two systems for cooling are worthy of attention; the forced oil, and the forced water system. The latter is preferable for the following reasons: First, because the required piping is less and the cooling water for all transformers may be supplied by one pump. This system is less expensive to install and more convenient to operate. Secondly, the cooling coils inside the transformer can be made absolutely water tight by welding at the factory, while in the forced oil system the piping in the tail-race must be made up in the field, and as it is submerged the inspection and repair is very difficult. Thirdly, when necessary the oil can be withdrawn with much less difficulty from the transformer. Fourthly, the indicating device to show the cooling system is in operation is much more simple.

The transformer oil should be tested regularly by means of a spark gap and testing transformer, and, when deterioration shows, should be treated either by drawing or blowing heated air through the oil, or by filtration through lime and sand. The latter method is recommended for the following reasons: First, the floor space required is small. Secondly, the speed of filtration may be adjusted according to the degree of deterioration. Thirdly, only one oil pump is necessary for the whole system. Fourthly, oil showing only slight deterioration may be circulated through the filter tank and back to the transformer without interrupting the operation of the transformer.

Regarding the high tension connections of a bank of transformers, there are two principal systems in common use; namely, the ungrounded delta, and the Y connection with the grounded neutral. The delta connection has the advantage, on account of the non-existence of the combination of capacity in series with a large enough inductance at times of an accidental arcing ground with the low-tension transformer winding also accidentally opened, resonance with high power effects cannot take place. It has the other advantage that if one line conductor gets grounded, the service need not necessarily be interrupted except perhaps if the ground is an arcing ground which would set up a continual high frequency surge producing high potential strains on the station apparatus. It has been claimed that the ungrounded delta system would come more into favor due to the ability of the new electrolytic type of lightning arrester to take care of continued high voltage surges. The writer has, however, experienced several instances where this kind of arrester in a delta-connected system became disabled apparently by the effect of inductive disturbances in the system due to improper switching operations, and the very strong claims which the manufacturers make for this construction are not fully borne out in practice. It would seem wise, therefore, not to depend too much upon the electrolytic type of arrester in claiming the advantages of a delta-connected system.

International Electrotechnical Commission

RESUME OF THE WORK OF THE UNOFFICIAL CONFERENCE, HELD AT BRUSSELS, AUGUST 8, 9 AND 10, 1910.

I. The Conference was opened by Colonel R. E. Crompton, C.B.

II. Professor Eric Gerard, President of the Belgian Electrotechnical Committee, welcomed the foreign Delegates and Representatives.

III. The Honorary Secretary, Col. Crompton, read a report on the work and general progress of the Electrotechnical Commission.

IV. Professor Eric Gerard was elected to preside during the Congress.

V. NOMENCLATURE

The Honorary Secretary read a report on the subject.

A long discussion took place and ultimately the Conference expressed the desire that the following propositions be submitted to the Electrotechnical Committees:

1. That the list proposed by the German Committee be taken as basis for the next step in the work of Nomenclature. A limited number of fundamental terms may be added to this list.
2. That this list be considered by the Committees so that each Committee may draw up definitions corresponding to the terms in the proposed list; the definitions to be drawn up in English and in French and the term corresponding, when it exists, to be given in English and in French and in the language of the country of the respective Committee.
3. That the work of the Committees be sent to the Central Office as soon as possible before the 1st March, 1911.
4. That the British, French and German Committees should each choose one Delegate; these Delegates should meet between the 1st March and the 1st September 1911 in order to compare the work mentioned in Paragraph 3, and will do their utmost to prepare a list of agreed definitions. In drawing up this list the international character of a large number of technical terms shall as far as possible be taken into account. This list shall be submitted to the Commission at its next meeting.
5. That the extension of the list proposed by the German Committee be reserved. At the same time any Committee desiring to continue the alphabetical lists already commenced shall be at liberty to do so, and to communicate directly with each other upon this subject.
6. That in order to ensure the homogeneity and coördination of the definitions and of the terms, the French Committee, with the assistance of the Belgian Committee, be requested to undertake the preparation of a logical list of fundamental ideas in such a manner that one definition leads naturally to the next. These definitions to be gathered into groups, certain leading ideas being taken as the starting point for each group. This list to be presented to the Commission at its next meeting with a view to its being proposed as a basis for the future lists of terms of the vocabulary.

VI. SYMBOLS

After discussing the proposals of the French Committee the Conference expressed the desire that the following propositions be submitted to the Electrotechnical Committees:

1. That small letters be reserved for the representation of the instantaneous values of electrical quantities which vary with the time.
2. That capital letters be reserved for the representation of effective or constant values of electrical quantities.

3. That capital letters followed by the subscript " m " be reserved for the representation of the maximum values of periodic electrical quantities.
4. That capital script letters be reserved for the representation of magnetic quantities, constant or variable.
5. That capital script letters accompanied by the subscript " m " be reserved for the representation of the maximum values of magnetic quantities.
6. That the following letters be reserved for the representation of the following quantities:

Electromotive force	E, e
Electric quantity	Q, q
Inductance	$\mathcal{L}$
Magnetic force	$\mathcal{H}$
Magnetic flux density	$\mathcal{B}$
Length	*L*, l
Mass	M, m
Time	T, t

VII. Direction of Rotation for Vectors

This question was brought to the notice of the Conference by the Committee of the United States of America.

The Conference expressed the desire that this question be studied by the Electrotechnical Committees with a view to the preparation of a proposition for the next meeting of the Commission.

VIII. Rating of Electrical Machines

After a general exchange of ideas the Conference expressed the desire that the following propositions relating to the power of continuous current machines be submitted to the Electrotechnical Committees:

1. That the output of electrical generators be defined as the electrical power available at the terminals.
2. That the output of electrical motors be defined as the mechanical power available at the shaft.
3. That both the electrical and mechanical powers be expressed in international watts.

New Institute Branches

At the meeting of the Board of Directors of the Institute held on November 11, 1910, two new Branches were authorized as follows:

University of Vermont, Burlington, Vermont,

University of Oregon, Eugene, Oregon

Past Section Meetings

Atlanta

The Atlanta Section held its regular monthly meeting in the Equitable Building, Atlanta, Ga., on November 9, 1910. Twenty-six members and visitors were present. The meeting was devoted to a discussion of Professor V. Karapetoff's treatise on the calculation of necessary reactive kilovolt-amperes derived from synchronous condensers for correcting power-factor from any given amount to any required amount. Those taking part were, Messrs. H. P. Wood, J. N. Eley, F. B. Davenport, G. I. Yundt, and E. P. Peck.

Baltimore

The opening meeting of the Baltimore Section for the year 1910-1911 was held at the Johns Hopkins University, Baltimore, Md., on October 28, 1910. A paper entitled " The Development of the Moore Vacuum Tube Light " was presented by Mr. D. McFarlan Moore. Mr. Moore gave an interesting historical account and a practical demonstration of the present high state of development of this method of lighting. One hundred and twenty-one members and visitors attended the meeting.

Boston

A joint meeting of the Boston Section in coöperation with the Boston Society of Civil Engineers and the American Society of Mechanical Engineers was held in Chipman Hall, Tremont Temple, Boston, on October 19, 1910, A paper entitled " An account of the Destruction of Cartago, Costa Rica,

by the earthquake of May 4, 1910" was presented by Professors Thomas A. Jaggar, Jr., and Charles M. Spofford. Professor Jaggar spoke of the geological features, and Professor Spofford discussed the effects of the earthquake on different classes of structures. The lecture was illustrated by stereopticon views of Cartago taken shortly after the earthquake, and by views of other Central American scenes. About 70 members were present.

Another joint meeting of the three societies was held in the auditorium of the Edison Electric Illuminating Company on November 10, 1910. At this meeting a paper entitled "Smoke Abatement in New England" was presented by Mr. D. T. Randall, engineer. The paper was discussed by Messers. I. E. Moultrop, E. G. Bailey, F. H. Keyes, Charles H. Bigelow, and John T. Hawkins. Written communications were read from Messrs. Charles H. Manning, Henry Bartlett and G. H. Barnes.

Chicago

The first of the series of joint meetings of the Chicago Section and the Electrical Section of the Western Society of Engineers for the season of 1910–1911 was held in the Fullerton Memorial Hall of the Art Institute, Chicago, Ill., before an audience of approximately 400 members of both organizations. Mr. J. W. Alvord, president of the Western Society of Engineers, presided. Dr. C. P. Steinmetz, of Schenectady, N. Y., delivered a lecture on "Industrial Importance of Electrostatics and Electric Impulse Forces."

Ithaca Section

A special meeting of the Ithaca Section was held in Sibley Hall, Cornell University, Ithaca, N. Y., on October 7, 1910. Mr. George S. Macomber was elected secretary, succeeding Mr. B. C. Dennison, resigned. Mr. W. E. Lee was elected student representative member of the executive committee. Chairman E. L. Nichols gave a brief account of the Section delegates' conference at the Jefferson Convention, and Professor V. Karapetoff gave a brief resumé of the papers presented at Jefferson. Mr. W. C. Wagner gave an account of his observations of electrical engineering practice in the State of Washington. This meeting was held chiefly for the purpose of presenting the object of the Ithaca Section to the new students. The attendance numbered about 130 members and visitors.

Madison, Wis.

The first meeting of the Madison Section for the season of 1910–1911 was held on Wednesday evening, November 9, 1910. A paper was read by Mr. M. H. Collbohm, chairman of the Section, on "Transformer Installations," an abstract of which is published elsewhere in this issue. Professor M. C. Beebe made a report of the Jefferson Convention, which he attended as a representative of the Madison Section. In the business session which followed, Mr. M. H. Collbohm was reelected chairman, and Mr. H. B. Sanford was reelected secretary. A set of by-laws were adopted by vote.

Mexico

The November meeting of the Mexico Section was held in the Mexican Schools of Mines, Mexico City, on November 4, 1910. A paper entitled "Design and Operation of Gas Engines" was read by Mr. T. R. Bremmer. The paper was of a general nature, and dealt at considerable length with the difference between European and American practice in the design of gas engines of the larger sizes. Mr. Bremmer also spoke at some length on the conditions affecting the paralleling of alternators driven by gas engines, and indicated some features of modern design which tend to keep down hunting

troubles when gas-engine-driven alternators are operated in multiple.

Milwaukee

The Milwaukee Section held a joint meeting with the Engineers Society of Milwaukee on September 21, 1910, with an approximate attendance of 60 members of the two societies. Dr. Eric R. Miller, of the United States Weather Bureau, Madison, Wis., presented a paper on " Forecasting the Weather."

Another joint meeting with the Engineers Society was held on October 12. Mr. Mark R. Lamb, of the Allis-Chalmers Company, read a paper on " Mining Machinery Applications."

Philadelphia

The Philadelphia Section held its regular meeting on November 14, 1910. In the absence of the chairman, Mr. C. I. Young, Professor George A. Hoadley occupied the chair. One hundred and twenty members were present. The subject of the evening was a lecture on " The Optics and Physiology of Kinemacolor," by Mr. G. H. Aymar, general manager of the Kinemacolor Company of America. Mr. Aymar showed a number of moving picture films in which the objects shown appeared in their natural colors, and explained how the result was attained. There was considerable discussion by Messrs. Bryan, of Hawaii, Professor Montgomery, of Santa Claire University, Cal., Professor Hoadley, Dr. Northrup, Dr. Keith, and Messrs. James, Hornor, Sharer, Hering, Snook, Bartlett, Chilton, and others.

Pittsfield

The second meeting of the Pittsfield Section for the season was held in the Wendell Hotel, Pittsfield, Mass., on October 27, 1910. It was preceded by a dinner at which Mr. Ralph W. Pope, Secretary of the Institute, was one of the guests. The speaker at the meeting was Mr. A. McK. Gifford, who gave a lecture on " The Chemistry of Mineral Oils ". At the close of the discussion which followed the paper, Chairman Blake introduced Mr. Pope, who spoke of the work of the Institute and the part it was taking in the various national movements. In closing he referred to the proposed mid-year convention of the Schenectady-Pittsfield Sections to be held in February. An abstract of Mr. Gifford's lecture is printed elsewhere in this issue.

Portland, Oregon

The first meeting of the Portland Section for the season was held on October 18, 1910. Thirty-two members were present, with Chairman L. B. Cramer presiding. Mr. H. P. Wakeman, who represented the Portland Section at the Jefferson Convention of the Institute, gave an outline of his experience there, and a brief summary of the papers presented. The technical part of the program consisted of two papers by Mr. S. Ring, of W. S. Barstow and Company, and Mr. H. A. Kirtland, of the Home Telephone Company, on " Underground Construction." Mr. B. S. Durkee, of the Postal Telegraph Company, also gave a short talk on that company's method of underground construction. The papers were particularly interesting to the Portland members, on account of the new underground systems being installed in Portland.

San Francisco

The San Francisco Section held its regular meeting in the Home Telephone Building, San Francisco, on October 28, 1910. The following amendment to the Section by-laws was adopted: " The Executive Committee elected for the ensuing year shall organize by electing from their number a chairman and vice-chairman, and shall elect from among the membership of the Section a secretary-treasurer, to serve for not

more than one year." Mr. Edward L. Haines was subsequently appointed secretary. A paper of unusual interest, on "The Problem of Technical Education, with Special Reference to Conditions on the Pacific Coast", was presented by Messrs. S. B. Charters, Jr., and W. A. Hillebrand. The subject, in its various aspects, was discussed by Messrs. Brooks, Van Norden and Lisberger.

St. Louis

The fifty-seventh meeting of the St. Louis Section was held on Wednesday evening, October 12, 1910, in the rooms of the Engineers Club of St. Louis, Chairman Lamke presiding, with 24 members and visitors present.

The resignation of Mr. F. W. L. Peebles as secretary, owing to his removal to Milwaukee, was accepted. Among other business transacted at the meeting a committee was appointed to draft suitable by-laws to govern the administration of Section affairs. Professor Langsdorf then gave a report of the Jefferson Convention of the Institute which he attended as representative of the St. Louis Section.

At a meeting of the Executive Committee held on October 29, Mr. Oddgeir Stephenson was elected secretary, and plans for the winter were discussed.

Schenectady

The opening event of the Schenectady Section for the season was a smoker and informal gathering given on October 25, 1910. Among the out of town guests present were Mr. Gano Dunn, vice-president and chief engineer of the Crocker-Wheeler Company, and Mr. Ralph W. Pope, Secretary of the Institute. Mr. Dunn gave an address on the necessary qualifications of an engineer, and Mr. Pope spoke on the importance of social intercourse among engineers. Among other speakers were Dr. C. P. Steinmetz, Mr. W. B. Potter, and Mr. A. L. Atkinson. The attendance numbered over 350 members, and the event proved an unqualified success.

The first regular meeting of the Section was held on November 1, when Dr. W. R. Whitney, director of the General Electric Company's research laboratory, addressed the members on the history of artificial illumination and the more recent applications of chemistry to modern illuminants. A set of photographs of the interior of the Soldiers' Memorial Building at Pittsburg was shown as an example of the modern tendency of architects to pay increased attention to the illuminating features of buildings. The attendance at this meeting numbered about 250 members.

Toledo

The regular meeting of the Toledo Section was held on Friday, November 4, 1910, in the rooms of the Y.M.C.A. Mr. W. A. Hill, electrical engineer in charge at the Willys-Overland Company's plant, delivered an address on "The Selection and Installation of the Electrical Equipment for a Large Industrial Plant." The speaker went into the problem of motor ratings and distribution lines therefor, and dwelt at some length on the disposal of equipment for maintenance and repair. Many points of interest in trouble work were brought out. The address was received with much favor, and ended in a general discussion by Messrs. C. B. Cook, Max Neuber, Paul Horan, W. E. Salber, C. B. Nickles, John Gilmartin, and George E. Kirk.

Toronto

The November meeting of the Toronto Section was held in the rooms of the Engineers' Club, Toronto, on November 18, 1910, with a total attendance of 64 members and visitors. The subject of the meeting was a paper presented by Mr. J. H. Vail, of the General Equipment Company, New York. Mr. Vail traced the history of the electric vehicle from its earliest

development to the present time. Among the features brought out by the speaker might be mentioned the notable progress made in the development of the storage battery and the electric motor for vehicle work, and the great extent to which the electric vehicle has been adopted for commercial service during recent years.

Urbana

A meeting of the Urbana Section was held at the University of Illinois on October 19, 1910. The paper on "Potential Stresses in Dielectrics" presented at the Institute meeting in New York on October 14 by Mr. Harold Osborne, was abstracted by Mr. T. D. Yensen, and then thrown open for discussion. Mr. Yensen mentioned some of his experiences in the use of cables with the Shawinigan Power Company. Among other things he spoke of the use of three-phase, single conductor cables spanning the river near Montreal which were continually giving trouble. These were later armored, but as they were suspended in the water, gave no noticeable heat; yet they broke down quite frequently. A three-phase cable for 25,000 volts was later purchased and put in parallel with these single conductor cables. This gave no trouble, but after many tests were carried on, it was discovered that the single conductor cable would not carry any current when in parallel with the three-wire cable. The single conductor cables were abandoned. Another point touched upon in the discussion was the subject of corona in solids and in fluids. The results of tests carried on in oil at the University of Illinois during the past year were mentioned. Either the electrostatic stresses in the oil, or what is equivalent to corona in air gave very erratic results with standard oil testing apparatus when used for voltages higher than normal. The oil tests will be conducted during the present year with a view to standardizing an apparatus for this purpose. Later it is hoped to follow this by complete tests on oil for transformers and switches. It seems reasonable to suppose that a similar stress could exist in solids, but how a strain could be produced for any thickness in the solid by these stresses is hard to imagine. Tests carried on with solid dielectrics do not seem to bear this out in every particular. At the present time the testing of insulation of all types is in an unsettled condition. It is hoped that the method of testing may be standardized during the year by the bodies interested.

Washington, D. C.

The November meeting of the Washington Section was held in the Telephone Building, Washington, D. C., on November 8, 1910. The papers presented were, "Searchlights in the Navy," by Commander S. S. Robison, U. S. Navy, and "Searchlights in the Army," by Lieutenant William H. Rose, Corps of Engineers, U. S. Army. Commander Robison's paper included a historical sketch of the development of electric lighting from the earliest attempts with primary batteries to the highly developed and powerful apparatus of today. Lieutenant Rose's paper was equally interesting, dealing with the subject from a military standpoint and including an interesting exhibit of lantern slides showing the practice in the army service both in this country and several foreign countries. An interesting discussion followed the papers, in which Mr. J. L. Hall, searchlight engineer of the General Electric Company, took a prominent part.

Chairman Wheeler announced that the executive committee is contemplating, in coöperation with the Washington Society of Engineers, the Baltimore Section of the A.I.E.E., and the Engineers Club of Baltimore, a trip in the spring to the hydroelectric plant of the Pennsylvania Power and Water Company at McCall's Ferry on the Susquehanna River.

Past Branch Meetings

University of Arkansas

A meeting of this Branch was held on October 25, 1910, at which Mr. P. L. Mardis gave a talk on the "Hydro-electric Survey of White River, Arkansas." Mr. Mardis spent all of last summer on this work, and showed many views taken on the trip.

The next meeting was held on November 9. Professor W. B. Stelzner gave a talk on a complete test of a synchronous converter. Plans were discussed for holding a social function early in December.

Armour Institute

The Armour Institute Branch held its first meeting on October 27, 1910. Mr. L. L. Williams read a paper on "Car Lighting". Mr. Williams pointed out the advantages of electric illumination for cars, and described several methods of car lighting in use at present. The advantages of the "head-end" the "axle-light" and the storage battery systems were discussed. The main part of the paper treated of the Bliss system, which uses a generator driven from a car axle. The operation of the various parts were explained. These included the generator, its suspension and method of driving, the automatic pole changer to take care of running the car in either direction, the operation of the automatic generator switch, the action of the "stop-charge" and "taper-charge" relays, the emergency excitation device, and the operation of the voltage regulator. The speaker provided those present with blue-prints of the Bliss system, which enabled everyone to follow closely and intelligently the action in the various circuits. Mr. Williams further discussed the mechanical and electrical difficulties encountered in such a system.

Bucknell University

The Bucknell University Branch at Lewisburg, Penn., which was authorized last May, held its first regular meeting on October 15, 1910. A paper was read by Mr. H. K. Rhodes, on "Electrical Engineering Education."

Case School of Applied Science

The first regular meeting of the Case School Branch, Cleveland, Ohio, was held on the evening of October 11. Short talks were given by Professor Dates, Professor Rowell, Mr. Clark and Mr. Zarbinsky on summer experiences. Professor Dates told of his trip last June to attend the Jefferson Convention. Professor Rowell and Mr. Clark spoke of their summer visits. Mr. Zarbinsky related his experience in helping to develop a high frequency machine. By means of sketches and diagrams he explained the construction of the apparatus and its use on either alternating or direct current circuits. Thirty-seven members were present.

The meeting of October 24 was devoted to a discussion of Edison storage batteries. The following papers were presented: "Theory of Edison Storage Battery," by O. P. Sutton; "Construction of Edison Cell," by H. A. Harrington; "Comparison of Edison to Lead Cell," by W. J. Hering.

The subject of electric steel furnaces was discussed at the meeting of October 31. Three papers were read, as folows: "History and Development of Electric Steel Furnaces," by E. F. Sipher; "Modern Types of Steel Furnaces," by R. J. Hoddinott; "Comparison of Electric to Coal Furnaces," by D. C. Orwig.

On November 7 the subject of electric car lighting was presented and discussed in three papers by Messrs. H. G. Grover, D. N. Hanchette, and T. W. Rutledge. The papers dealt with street car lighting, electric train lighting, and lamps used in car lighting.

Colorado State Agricultural College

A meeting of this Branch was held on November 2 for the purpose of interesting the new students and increasing the membership. Professor F. A. De Lay addressed the members on "The Purpose of the Institute." Professor Standt gave a talk on "The Value of Practical Work with a Technical Education." Dr. Lory gave a brief address on "The Resources of Colorado." Refreshments were served.

University of Colorado

Meetings of this Branch were held on October 19 and November 2. At the October meeting Mr. J. B. Morrill discussed the subject of applications of analytic geometry to engineering formulas, giving blackboard illustrations. At the November meeting Mr. V. C. Moulton gave a talk on metallic filament lamps.

Iowa State College Branch

The Iowa State College Branch resumed activity on October 5, and meetings were subsequently held on October 19 and November 2. On October 5 Mr. Fred M. Benbow gave an abstract of the paper by John W. Howell, on "Metal Filament Lamps," appearing in the June 1910 Proceedings. The meeting of October 19 was devoted to a discussion of the Pennsylvania tunnel by Messrs. R. J. Barry, C. H. Cooley, and O. A. Eastwald. On November 2 Professor W. H. Meeker gave a talk on the subject of "The Electric Furnace as Applied to the Manufacture of Steel," in which he described the various furnaces in use and the relative merits and demerits of each. One hundred and twenty members and visitors were present at this meeting.

State University of Iowa

Two meetings were held by this Branch, on October 10 and October 24, respectively. On October 10 Mr. E. W. Hatz reviewed Dr. Samuel Sheldon's paper on "Leadership in Electrical Engineering," appearing in the April 1910 Proceedings. On October 24 Mr. F. H. Bates gave a review of the *London Electrician* for September 1910. Mr. L. L. Darner read the paper by Mr. John W. Howell on "Metal Filament Lamps," which was published in the Proceedings for June, 1910.

Kansas State Agricultural College

The first regular meeting of this Branch was held on November 1, 1910. The following papers were presented: "History and Development of the Carbon Lamp," by R. H. Reynolds; "The Tantalum Lamp," by Homer Sloan; "The Tungsten Lamp," by S. M. Ransopher. Twenty-one members attended the meeting.

University of Kansas

The University of Kansas Branch held meetings on October 26 and November 9. The October meeting was given over to a discussion of the electrification of steam railroads. The program of the November meeting consisted of a paper by Mr. C. H. Chapman, entitled "Starting a Rotary Converter System from Rest," and an abstract of current electrical literature by Messrs. Thomas Steeper and C. V. Waddington.

Lehigh University Branch

The November meeting of the Lehigh University Branch was held on Tuesday evening, November 8, 1910. In a paper entitled "Induction Furnaces," Mr. H. E. Ramsey gave a description of the various types of induction furnaces now in use. Mr. C. D. Kafer, electrical engineer, of the Bethlehem Steel Company, followed with a paper on "General Crane Specifications." Professor W. S. Franklin explained in detail Bernoulli's "Principle of Hydraulics", accompanying his talk with experiments and lantern slides.

University of Maine

A meeting of the University of Maine Branch was held at Orono on October 14, 1910. The election of officers for the ensuing year resulted as follows: Chairman, A. T. Childs; vice-chairman, R. Reid; secretary, F. L. Chenery; treasurer, J. Robinson. Mr. Merrill read a paper on "The New England Telephone Company." Mr. Royal told of his work with the General Electric Company at Schenectady.

At a meeting held on October 28, 1910, a lecture on the subject, "Manufacture of Fertilizers by the Use of Electrical Energy" was given by Professor C. W. Easley. Professor Easley took up the chemical reactions which must take place to form a suitable nitrate. He then showed how it was possible to obtain the high temperature necessary by use of the electric arc. Extracts were given from the experiments of Berhelund and Eyde, the Norwegian chemists, and Schoenherr, the German chemist. Dimensions of electric furnaces and the form of arc used were given, also figures as to the amount of fertilizer that could be manufactured annually and the cost of the same. The present efficiency was considered low, and as a result such a plant would be a commercial failure in America.

On November 16 the Branch was addressed by Mr. A. H. Blaisdell, on "The Gas Engine as Adapted for Use in Electrical Development." Mr. Blaisdell stated that there were three periods in the development of the gas engine: (1), the period of theory; (2) the period of invention; (3) the period of practical use; the latter covering the last 15 years, and brought about largely by the diminishing supply of fuel. He divided gas engines into three branches: (*a*) stationary; (*b*) automobile; (*c*) marine. The stationary engine alone was discussed in detail, and particular attention was paid to the methods of governing, in its relation to use in electrical plants.

University of Michigan

Professor G. W. Patterson addressed a large audience at the opening meeting of this Branch on October 2, 1910, on the subject "Mountain Railroads in Switzerland." Professor Patterson stated that in contrast with American electric railroads the Swiss railways all use alternating current, the three-phase motor being the most common. These motors possess many advantages over those using direct current as no power is wasted on the steep grades, and brakes are not used on descents. Professor Patterson discovered that many of the railways in Switzerland have gone back to the use of steam, and he was disappointed to find, after passing through the Simplon tunnel, that he had been drawn by a steam locomotive. In a description of the railway up the New Jungfrau he stated that the steep grades have made it necessary to use an electric current for the last part of the ascent. "In speed and comfort the American roads are far superior to the European", concluded Professor Patterson, "but the foreign trains are much more dependable and prompt." Professor de Muralt closed the meeting with a brief account of the American Institute of Electrical Engineers, and urged all students in his department to join the Branch.

At the meeting held on November 16 Professor B. F. Bailey gave a lecture on "The Cost of Electrical Machinery." He outlined and explained a scientific basis for the arrangement of prices of electrical machinery. Professor Bailey has done considerable work along this line. This is the first opportunity that the students have had of obtaining factory cost data, which has always been guarded as a trade secret.

University of Missouri

The University of Missouri Branch held its regular meeting on October

24, 1910. The two members of the executive committee elected in the spring announced their selection of the third member in accordance with the authority conferred upon them at the time of their election. The personnel of the committee is now as follows: T. S. Haddaway, E. W. Stapf, and F. P. Huston. Dr. Herman Schlundt gave an account of the papers and discussions at the meetings of the American Electrochemical Society in Chicago.

Montana State College

At the meeting of the Montana State College Branch on November 4, Dr. J. M. Hamilton, president of the college, gave a talk on "Economics of Promotion." He explained the value of coöperation in the development of our resources, and the relation between capital and labor. He then outlined the theories of the creation and distribution of wealth, the organization of corporations, and the opportunities for legitimate promotion of engineering projects in Montana.

University of Nebraska

The first regular executive meeting of the University of Nebraska Branch was held for the purpose of organizing a campaign for the coming year. It was decided to adopt a program for the entire year, and Secretary Hollister was empowered to complete the details.

Oregon Agricultural College, Corwallis, Oregon.

A special meeting of the Oregon Agricultural College Branch was held on October 27, 1910, for the purpose of electing officers for the year. Those elected were: Chairman, LeRoy V. Hicks; secretary and treasurer, Charles A. French; executive committee, Professor T. M. Gardner, Dr. W. Weniger, Messrs. F. R. Shepard, Darwin Carnegie, LeRoy V. Hicks.

The first regular meeting of the Branch was held on November 7. It was decided that the members of the Branch will take up the study of illuminating engineering. The subject will be covered in 14 papers, two of which will comprise the main part of the program of each succeeding meeting. Professor T. M. Gardner gave a talk regarding the advantages of affiliation with the A.I.E.E.

Purdue University

The first program meeting of the Purdue University Branch for the year was held on Tuesday evening, October 4, 1910. Professor C. Francis Harding, head of the electrical engineering department, was the speaker of the evening, and his subject was the "New Electrical Power Plant at Purdue." The new shops for the department of practical mechanics, consisting of machine shop, wood shop, forge room, and foundry, have been completed, and since the machinery in each of these shops is to be electrically driven, additional generating equipment became necessary. As a result, the re-design and reconstruction of the electrical plant and distributing system followed. Professor Harding described the old two-phase system and explained its limitations. He then discussed in detail the motor installation in the new shops. The new generating unit to be installed will consist of a 250 kw., three-phase generator, direct connected to a high speed engine. The old two-phase unit is to be operated in parallel with the new three-phase unit through Scott transformers. Direct current for a few shop motors and projecting lanterns is to be supplied from a 25 kw., 220-volt, three-wire motor generator set. The motor of this set is to be operated directly from the 2,200-volt, three-phase bus bars. Professor Harding explained the advantages of the three-phase system as compared with the two-phase system, and showed how alternating current motors are safer and better for shop use than direct current machines. He further illustrated his lecture by a sketch of the new

power-house switch board, which consists of the following: two generator panels, a distributing panel, a motor generator panel, and a panel for the Tirrell regulator controlling the bus bar voltage. A 15-minute discussion followed.

On October 18 Professor Philip S. Biegler gave an address on "Hydroelectric Power Plant Construction." His talk consisted largely of personal experiences while in the employ of the Washington Water Power Company. To illustrate his points he made a sketch of Eastern Washington and Northern Idaho, showing the roughness of the country. The load of the company is distributed to the extent of requiring transmission lines of over 100 miles in length in several directions from Spokane. Coal and water power are both available for the purposes of generation, but on account of the high cost of coal and the excellent power sites along the Spokane River, water power is almost entirely used. The Little Falls plant, which was described in particular, is a 36,000 h.p. development just nearing completion, and represents the latest practice in hydroelectric plant construction. The transmission lines to Spokane are also deserving of special mention, the aluminum conductors being hung with suspension insulators from steel tower lines.

Syracuse University

At the first meeting for the year, of the Syracuse University Branch, Dr. W. P. Graham, chairman of the Branch, presented a paper on "The Hunt Cascade Motor," showing that this machine, which has a short-circuited rotor and no slip rings, can be operated as a variable speed motor, and further, that the manufacturing cost would in all probability be less than that of the usual squirrel cage motor of the same capacity and speed. When fitted with slip rings the Hunt cascade motor can be operated at two efficient speeds.

Agricultural and Mechanical College of Texas

The first regular meeting of this Branch was held on November 12, 1910, and the following officers were elected: Chairman, L. S. Peter; secretary, Hy. Louwien, Jr. The program, consisting of several talks, was as follows: "The Diesel Gas Engine", by M. Taylor; "Boiler Room Economy", by C. P. Dodson; "Gas Electric Motor Cars", by Hy Louwien, Jr.

University of Texas

The University of Texas Branch has reorganized for the year with the following officers, elected at a business meeting held on October 27: Chairman, B. E. Kenyon; secretary and treasurer, J. A. Correll; executive committee, G. H. Brush, chairman, Carl Lee, and R. T. Cole. Twenty-five members were present at this meeting.

Washington University, St. Louis, Mo.

The first meeting of this Branch, for the season, was held on October 17, 1910. Mr. W. G. Nebe was elected secretary-treasurer. It was decided to hold regular meetings on the last Wednesday of each month. There being no further business, the meeting was turned over to the members present, some of whom gave accounts of their experience during the summer. Refreshments were served after adjournment.

The next meeting was held on November 8. Messrs. Pieksen and Hardy presented a paper on "The Mercury Arc Rectifier." Mr. Hardy treated of the theory of the rectifier, while Mr. Pieksen gave an explanation of its manipulation and uses.

Washington State College, Pullman, Washington

This Branch reorganized at a meeting held on October 25, 1910, and the following officers were elected: Chairman, M. K. Akers; secretary, H. V. Car-

penter. It was decided to hold weekly meetings. Accordingly, a meeting was held on November 1, and another on November 8. Mr. H. W. Tobey's paper on "Dielectric Strength of Oil," presented at the Jefferson Convention of the Institute and appearing in the July PROCEEDINGS, was abstracted by Mr. R. Marston, at the meeting of November 1. On November 8 Mr. C. A. W. Dawson reviewed the paper on "Potential Stresses in Dielectrics," by Osborne and Pender, appearing in the October PROCEEDINGS.

WORCESTER POLYTECHNIC INSTITUTE

An audience of 400 members and their friends attended the opening meeting of the Worcester Polytechnic Institute Branch on October 14, 1910, to hear a lecture by Professors Phelon and Knight on "Electricity and Some of Its Applications." The lecture was accompanied by experimental demonstrations in which special stress was laid on illumination problems, these being fully illustrated by the use of apparatus lent for the purpose by the General Electric Company. Special attention was given to a comparison of alternating and direct current lighting systems, and several interesting stroboscopic experiments were performed. Peculiar color schemes were obtained by means of an "electric rejuvenator", in which various forms of lighting combined to produce most amusing and unexpected results. After the lecture refreshments were served and the laboratory was opened for inspection.

The second meeting was held on October 28. Four members of the Branch told of their summer experiences. Mr. H. E. Hartwell gave a report of the Jefferson Convention. Mr. H. V. Leckie spoke of the automatic switches of the Pennsylvania Tunnel and Terminal Company. He told of the care taken to make signal and switch connections durable, and gave an idea of the principles of operation of some of the switches. Mr. A. L. Atherton related many incidents in connection with his work as equipment man in the Darlington, R. I., long distance telephone station. A part of his talk was devoted to storage batteries and the internal combustion engine of the plant. Mr. H. E. Carrico spoke of the electrical engineering department of the Boston Elevated Railway Company. He explained cable and car testing, and went also into the details of signaling.

At the meeting of November 11, Mr. Fred H. Smith gave a talk on "The New Power Plant of the Worcester Electric Light Company." One hundred and ten members were present.

Personal

MR. JAMES J. FOX, electrical engineer, formerly of Newark, N. J., is now with the Commonwealth Edison Company of Chicago, Ill.

MR. GROVER G. REHFELD, is now engineer and superintendent for the Yellowstone Portland Cement Company, at Gardiner, Montana.

MR. CHARLES D. COLE of the Kankakee Power Company, Kankakee has resigned his position preparatory to locating in the South.

MR. J. E. MUHLFELD has been elected vice-president and general manager of the Kansas City Southern Railway Company, with headquarters at Kansas City, Mo.

MR. ALFRED GREEN, mechanical engineer, Galena Signal Oil Company, has removed from 147 Montague Street, Brooklyn, N. Y., to 483 Jersey Avenue, Jersey City, N. J.

MR. CHARLES F. CAMP, until recently with the Rumsey Pump and Machine Company, New York, has been appointed branch manager of the New England Engineering Company, at New Haven, Conn.

MR. L. B. CRAMER, electrical engineer of the Oregon Electric Railway Company, has been appointed electrical engineer of the United Railways Company.

MR. J. H. POOLE until recently a captain in the corps of engineers United States Army, has opened an office as consulting engineer in the Ford Building, Detroit, Mich.

MR. L. CLYDE CHATFIELD recently resigned from the construction department of the Brooklyn Edison Illuminating Company to take charge of similar work in London, England.

MR. H. R. STUART of the American Telegraphone Company, formerly at Wheeling, W. Va., is now located at Springfield, Mass., the factory of the company having been removed to that place.

MR. FRANK T. MANAHAN, electrical engineer with the Choctaw Railway and Lighting Company, has accepted a similar position with the Robin Hood Ammunition Company, Swanton, Vermont.

MR. C. MACMILLAN has left the Electric Control, Limited, of Glasgow, Scotland, to accept a position in the engineering department of the General Electric Company at Schenectady.

MR. J. H. PERKINS formerly manager of the Wilkes-Barre Gas and Electric Company, Wilkes-Barre, Pa., is now engineer with the Susquehanna Railway Light and Power Company, New York City.

MR. H. KEITH BODINE formerly engaged on power house designing with Clark, White and Clarke, is now resident and electrical engineer with the New York, Auburn and Lansing Railroad Company, Ithaca, N. Y.

MR. D. HASKELL has resigned as electrical engineer with the Vantanas Mining and Exp. Company, Ventanso, Durango, Mexico, and is taking a much needed rest at his home in Belleview, Florida.

MR. WALTER A. BELCHER, superintendent of the Jamaica division of the New York and Queens Electric Light and Power Company, has been appointed manager of the Gardner Electric Light Company, Gardner, Mass.

MR. A. L. SEARLES former manager of the Michigan territory for the Fort Wayne Electric Works has been appointed manager of the Rock Drill department of the same company with headquarters at Madison, Wis.

MR. LLOYD ESPENSCHIED, who has been with the Telefunken Wireless Telegraph Company, New York, is now in the engineering department of the American Telephone and Telegraph Company, New York.

MR. S. A. STAEGE has resigned as sales engineer with the Buffalo office of the Allis-Chalmers Company and has opened a consulting engineering office in the Smith Building, Watertown, N. Y.

MR. FRED C. ECKWORTH has resigned his position as draftsman with the Canadian General Electric Company, to accept a similar position in the direct-current machine department of the General Electric Company, Schenectady, N. Y.

MR. HARRY E. DUNHAM, for the past two years associate editor of the *Telegraph and Telephone Age*, New York, has resigned to accept a position as assistant examiner in the United States Patent Office, Washington, D. C.

MR. SAMUEL S. WATKINS has resigned his position in the testing bureau of the Brooklyn Rapid Transit Company,

to accept a position with Mr. Lewis B. Stillwell, on the Hoosac Tunnel electrification at North Adams, Mass.

MR. THOMAS W. WILKINSON has resigned his position in the plant department of the Missouri and Kansas Telephone Company at Kansas City, Mo., to accept a position as superintendent of the Emporia Telephone Company, Emporia, Kansas.

MR. E. L. BROCKWAY has resigned his position as superintendent of feeders of the Metropolitan Street Railway Company, New York, to accept a position as representative and construction engineer with Mr. T. J. Cope, of Philadelphia.

MR. R. N. FULTON, formerly erecting engineer with the British Westinghouse Electric and Manufacturing Company, Manchester, England, is now sub-station superintendent with the Auckland Electric Tramways Company, Ltd., Auckland, N. Z.

MR. ARTHUR R. DENNINGTON, for the past year engaged in the revision of the electrical engineering text-books for the International Correspondence Schools Ltd., has returned from London to take up instruction work for the same concern at Scranton, Pa.

MR. W. H. ORCUTT, until recently draftsman with the Pacific Telegraph and Telephone Company, San Francisco Cal., has accepted a position as electrical draftsman for the marine division of the Pacific Gas and Electric Company at San Rafael, Cal.

MR. EARL R. FILKINS has been transferred from the construction department of the Milwaukee Electric Railway and Light Company, to the electrical engineering department of the same company, Public Service Building, Milwaukee, Wis.

MR. G. ROSCOE MILFORD, has been transferred from the position of superintendent of the Kilarc division for the Northern California Power Company, to that of general superintendent and load despatcher for the same company, with offices at Volta, Cal.

MR. F. E. BOYD, who has been engaged in hydroelectric development work with the Klickitat Valley Development Company in Southwestern Washington, has resigned to accept a position in the sales office of the General Electric Company at San Francisco, Cal.

MR. H. P. CLAUSEN has resigned as chief engineer and general superintendent of the American Electric Telephone Company, Chicago, Ill., to accept a position as associate engineer with the Stromberg-Carlson Telephone Manufacturing Company, Rochester, N. Y.

MR. A. E. H. DINHAM-PEREN has resigned his position with the British Westinghouse Electric and Manufacturing Company, Manchester, England, and gone to South Africa to become assistant electrical engineer to the De Beers Consolidated Mines, Limited, Kimberly.

MR. M. B. WYRICK superintendent of construction and equipment with the Postal Telegraph and Cable Company, Dallas, Texas, has been appointed division plant superintendent of the Gulf division of the Western Union Telegraph Company with headquarters at Dallas, Texas.

MR. JOHN H. BRUNINGA formerly of the Examining Corps United States Patent Office, Washington, D. C., and associated with a Washington firm of patent lawyers, has opened an office in the Pierce Building, St. Louis, Mo., for the practice of patent, trade mark and copyright law.

Mr. Charles I. Young, for the past five years engineer for the Philadelphia sales office of the Westinghouse Electric and Manufacturing Company, has been transferred to the East Pittsburgh office to take up work in connection with the engineering activities of the sales organization.

Mr. J. C. Farrar, until recently electrical engineer with Buick Motor Car Company, Flint, Mich., has opened an office in the San Fernando Building, Los Angeles, Cal., under the firm name of J. C. Farrar and Company, consulting, constructing and contracting electrical engineers.

Mr. U. G. Dorn has resigned as master electrician of the Automatic Electric Company to take charge of dynamo and motor testing for the General Electric Company at Chicago. Mr. Dorn was married on November 2 to Miss Minnie L. Arbeiter, of Chicago. The ceremony was performed by the Reverend William Keller, former pastor of the Clifton Park German Methodist-Episcopal Church.

Mr. Charles E. Warner, formerly general superintendent of the Allegheny County Light Company, at Pittsburg, Pa., and who for some years has been engaged in handling electrical supplies in Los Angeles, was recently elected secretary and treasurer of the Southern California Oil Consumers Association and the Los Angeles Oil Consumers Agency, with headquarters at 330 Security Building, Los Angeles.

Library Accessions

The following accessions have been made to the Library of the Institute since the last acknowledgment:

Zur Beurteilung von Hochspannungs Freileitungs-Isolatoren nebst einem Beitrag zur Kenntnis von Funkenspannungen. By William Weicker. Berlin, 1910. (Gift of R. D. Mershon.)

Bureau des Longitudes. Annuaire 1911. Paris, 1911. (Exchange.)

Canadian Electrical Association. Proceedings of 20th Annual Convention. Toronto, 1910. (Exchange.)

Cities Service Company. Offering. 1910. New York, 1910. (Donor unknown.)

——Subscription Agreement. New York, 1910. (donor Unknown.)

Compendium of Applied Electricity. By P. E. Lowe. Philadelphia, David McKay, 1910. (Gift of publisher.) Price, 25cts.

Congreso Cientifico (I Pan Americano). Ciencias Quimicas. By B. D. Ossa. (Volume IV) Santiago de Chile, 1910. (Gift of CongresoCientifico).

Dynamo Electric Machinery; its Construction, Design, and Operation. Edition 8. By Samuel Sheldon and Erich Hausmann. New York, D. Van Nostrand, 1910. (Gift of publishers.) Price, $2.50 net.

Contents:—Chapter I. Electrical Laws and Facts. II. Magnetic Laws and Facts. III. Armatures. IV. Field Magnets. V. Armature Reaction. Commutation. VI. Generators. VII. Motors. VIII. Dynamotors, Motor Generators, Boosters and Storage Batteries. IX. Central Station Equipment.

Electric Power Plant Engineering. By J. Weingreen. New York, McGraw-Hill Book Co., 1910. (Purchase.)

Electric Wiring, Diagrams and Switchboards. By Newton Harrison. New York, N. W. Henley Pub. Co., 1909. (Purchase.)

Electrical Contracting. Ed. 2. By L. J. Auerbacher, New York. McGraw-Hill Book Co., 1910. (Purchase.)

Electrical Department of the District of Columbia. Annual Report 1910. Washington, 1910. (Gift of Electrical Department, District of Columbia.)

Electrical Engineer's Pocket-Book. Ed. 6. By H. A. Foster. New York, D. Van Nostrand, 1910. (Purchase.)

Electricity, Experimentally and Practically Applied. By S. W. Ashe. New York, D. Van Nostrand Co.,

1910. (Gift of publishers). Price, $2.00 net.

CONTENTS.—Chapter I. Magnetism. II. Electro-magnetism. III. Electro-magnetic Induction-Theory of the Dynamo. IV. Ohm's Law. V. Primary and Storage Batteries. VI. Electrolysis VII. Three-wire System. VIII. Electrical Measurements. IX. Shunt Motor. X. Series Motor. XI. Arc Light. XII. Incandescent Illuminants. XIII. Recording Wattmeters and their Use. XIV. Elementary Principles of Alternating Currents. XV. Alternating Current Transformer. XVI. Induction Motor. XVII. Rotary Converter.

Elektrische Beleuchtung. By B. Monasch. 2 Auflage Hannover, 1910. (Gift of Max Jänecke).

General Lectures on Electrical Engineering. Ed. 3. By C. P. Steinmetz. Compiled and edited by J. LeRoy Hayden. Schenectady, Robson & Adee, 1908. (Purchase).

History of the Telephone. By H. N. Casson. Chicago, A. C. McClurg & Co., 1910. (Gift of publishers.)

CONTENTS.—Chapter I. Birth of the Telephone. II. Building of the Business. III. Holding of the Business. IV. Development of the Art. V. Expansion of the Business. VI. Notable Users of the Telephone. VII. Telephone and National Efficiency. VIII. Telephone in Foreign Countries. IX. Future of the Telephone.

Institution of Electrical Engineers. List of Officers and Members. 1910. London, 1910. (Exchange.)

Lewis Institute. Register of 1909-10 (Bulletin October 1910) Chicago, 1910. (Gift of Lewis Institute.)

National Board of Fire Underwriters. List of Electrical Fittings that have been examined and approved by the Underwriters' National Electric Association. October, 1910. N.p. n.d. (Gift of National Board of Fire Underwriters.)

New Jersey Board of Railroad Commissioners. Annual Report 2d, 3d, 1908, 1909. Trenton, 1909, 1910 (Gift of New Jersey Public Utility Commissioners.)

Practical Illumination. By J. R. Cravath and Van Rensselaer Lansing. New York, McGraw Publishing Co., 1907. (Purchase.)

Practical Testing of Electrical Machines By Leonard Oulton and N. J. Wilson. New York, Whittaker & Co., 1909. (Purchase.)

Principles of Wireless Telegraphy. By G. W. Pierce, New York, McGraw Hill Book Co., 1910. (Purchase.)

Standard Wiring for Electric Light and Power. By H. C. Cushing, Jr. New York, 1910. (Purchase.)

Tesla High Frequency Coil, its Construction and Uses. By G. F. Haller and E. T. Cunningham New York, D. Van Nostrand Co., 1910. (Gift of publishers.) Price, $1.25 net.

CONTENTS.—Chapter I. General Survey. II. The Transformer. III. The Condenser. IV Oscillation Transformer. V. The Interrupter. VI. The Construction of the Boxes. VII. Assembling. VIII. Theory of the Coil. IX. Uses of the Coil. X. Dimensions of 7 inch Standard Coil.

Theory and Calculation of Transient Electric Phenomena and Oscillations. By C. P. Steinmetz. New York, McGraw-Hill Book Co., 1909 (Purchase.)

Treatise on Electro-Metallurgy. Ed. 3. By W. G. McMillan Revised by W. R. Cooper. London, Chas. Griffin & Co., 1910. (Purchase.)

Western Union Telegraph Company. Annual Report of the President to the Stockholders. 1910 New York, n.d. (Gift of Company.)

Wireless Telegraph Construction and Amateurs. By A. P. Morgan. New York, D. Van Nostrand Co., 1910. (Gift of publishers.)Price, $1.50 net.

CONTENTS.—Chapter I. Introductory. II. Apparatus. III. Aerials and Earth Connections. IV. Induction Coils. V. Interrupters. VI. Transformers. VII. Oscillation Condensers and Leyden Jars. VIII. Spark Gaps or Oscillators. IX. Transmitting Helixes. X. Keys. XI. Aerial Switches and Anchor Gaps. XII. Hot Wire Ammeter. XIII. Oscillation Detectors. XIV. Tuning Coils and Transformers. XV. Receiving Condensers. XVI. Telephone Receivers and Headbands. XVII. Operation.

Trade Catalogues.

Allgemeine Elektricitats Gesellschaft, Berlin, Ger. Motor dynamos for liquid fuels, their installations and operations. 16 pp.

——Vertical motors for driving centrifugal pumps. 60 pp.

Buff & Buff Mfg. Co., Boston, Mass. High grade engineering, surveying, and mining instruments. 117 pp.

Central Electric Co., Chicago, Ill. October 1910 price list of electrical supplies. 76 pp.

Crocker-Wheeler Co., Ampere, N. J. Index of Bulletins Nos. 70–125. 2 pp.

——Bull. No. 120—Form I machines, belt type, direct current motors 3¾ to 50 h.p., generators 3 to 45 kw. 15 pp.

——Bull. No. 122—Form D machines, belt type, direct current, motors 25 to 300 h.p., generators 45 to 250 kw. 7 pp.

——Bull. No. 123—Adjustable speed motors, .5 to 32 h.p. 15 pp.

——Bull. No. 125—Remek type transformers for light and power. 7 pp.

General Electric Co., Schenectady, N. Y. Mazda Street lamp price list No. 5237. 2 pp.

——Mazda incandescent lamp price list No. 536. 6 pp.

——Index to Bulletins, September, 1910. 10 pp.

——Bull. No. 4766—Tantalum incandescent lamps. 15 pp.

——Bull. No. 4768—Polyphase maximum watt demand indicator, type W. 7 pp.

——Bull. No. 4769—Train lighting with Mazda and Tantalum lamps. 15 pp.

——Bull. No. 4771—Hand-operated starting compensators for alternating current motors. 11 pp.

——Bull. No. 4772—Electric automobile appliances. 11 pp.

——Bull. No. 4773—Thomson high torque induction test meter, type IB-4. 4 pp.

——Bulletin No. 4774—Centrifugal air compressors for industrial air blast and exhauster service. 9 pp.

——Bull. No. 4776—Engine type continuous current generators, forms RB and RBO for lighting and power. 8 pp.

Locke Insulator Mfg. Co., Victor, N. Y. Insulators for electric work. 60 pp.

National Electric Lamp Assoc., Cleveland, O. Bull. No. 13—Mazda multiple lamps, 100–125 volts, and 200–250 volts, 25–500 watts. 19 pp.

——Bull. No. 14—Hylo economical turn-down electric lamps. 11 pp.

National Pneumatic Co., Chicago, Ill. Operating devices in the pay-within car. 15 pp.

UNITED ENGINEERING SOCIETY

Engineering News. Index, 1905–1909. New York, 1910. (purchase.)

Kelley's Directory of Engineers and Iron and Metal Trades. 1909. London, 1909. (Purchase.)

Modern Achievement. Vols. 1–10. New York, n. d. (Gift of J. A. Coles.)

Moody's Manual of Railroads and Corporation Securities. 1910. New York, 1910. (Purchase.)

New Century Reference Library. Vols. 1–8. New York, 1910. (Gift of J. A. Coles.)

Science-History of the Universe. Vols. 1–10. New York, 1910. (Gift of J. A. Coles.)

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Total, 36.

A paper to be presented at the 27th Annual Convention of the American Institute of Electrical Engineers, Jefferson, N. H., June 27–30, 1910.

VECTOR POWER IN ALTERNATING-CURRENT CIRCUITS

BY A. E. KENNELLY

It has long been known that in any simple alternating-current circuit, the current and voltage may be conveniently regarded as rotatable vector quantities.[1] It is also known that the power in such circuits is not to be regarded as the vector product of the rotating vector voltage and rotating vector current.[2] It does not seem to have been pointed out, however, that, under certain restrictions, it is proper to regard the power in an alternating-current circuit as a non-rotating vector quantity. Moreover, it does not appear to be generally known, although the fact has not escaped notice, that the imaginary component of vector power, or so-called "wattless power" is, in a restricted sense, just as much power, and just as "wattful" as the real component.[3]

The objects of this paper are:

1. To indicate the limitations under which power in an alternating-current circuit may be treated as a stationary vector;

2. To extend the technology of vector alternating-current quantities;

3. To combat the use of the terms "wattless power" and

1. J. A. Fleming, "Notes on Alternate Currents", "The Electrician", Nov. 18, 1887, Vol. 20, page 28.

2. Symbolic Representation of General Alternating Waves and of Double Frequency Vector Products, by Dr. C. P. Steinmetz, TRANSACTIONS A.I.E.E., Vol. 16, pp. 269–296. June, 1899.

The use of Complex Quantities in Alternating Currents, by Geo. W. Patterson, Physical Review, Vol. 26, No. 3, Mar. 1908, pp. 266–271.

3. The Improvement of Power Factor in Alternating-Current Systems, by Miles Walker, Journal of the Inst. of El. Engrs., Vol. 42, pp. 599–625, Jan., 1909.

" wattless current ", offering more logical terms as substitutes, and

4. To offer a plea for the standardization of the direction of phase rotation in the vectors used in alternating-current theory.

Preliminary Definitions. The vectors, or directed magnitudes, employed in alternating-current technology, with rare exceptions that do not come within the scope of this discussion, are all confined to a single plane of reference. That is to say, they relate to two dimensions of space, as distinguished from the vectors of three-dimensional geometry. This limitation may be expressed by saying that the vectors of alternating-current technology are *plane vectors.* A plane vector may be defined as a quantity having both a direction and a magnitude, but confined to one plane of reference. In what follows, we may for brevity conveniently assume that the term " vector " is an abbreviation for the more strictly logical term " plane vector ".

Subdivision of Vectors. There are three classes of vector used in dealing with alternating-current circuits, namely:

1. Vectors that are capable of rotation in their reference plane about a fixed point, and whose projections on a reference axis, or whose intercepts with polar curves, measure the instantaneous values of the quantities represented by the vectors. That is, the rotating vectors may be either *projected* or *intercepted.* These vectors may be called *rotative vectors.*

2. Vectors that are not capable of rotation in their reference plane for any purpose of projective or interceptive representation. These may be called *non-rotative vectors.*

3. Rotative-vectors that for special purposes are arrested, or treated as though non-rotative. These may be called *stationary vectors.* Stationary vectors are rotative, but non-rotating.

The above classification and nomenclature may be revealed more clearly by the following table:

TABLE I

Nomenclature and algebraic classification of alternating-current vectors.

Rotative ($l\ \underline{/\omega t}$)	....	Rotating ($l\ \underline{/\omega t}$)
	Stationary ($l\ \underline{/\omega T}$) (T = constant)	Non-rotating ($l\ \underline{/\theta}$)
Non-rotative ($l\ \underline{/\theta}$)		Non-rotating ($l\ \underline{/\theta}$)

Example of a Rotative Vector. As an example of class (1), let us consider the vector $O\,E$, Fig. 1, rotating in the plane $O\,X\,Y$, about the origin O, with a uniform angular velocity of ω radians per second. Then the length $O\,E$ may represent to an assigned

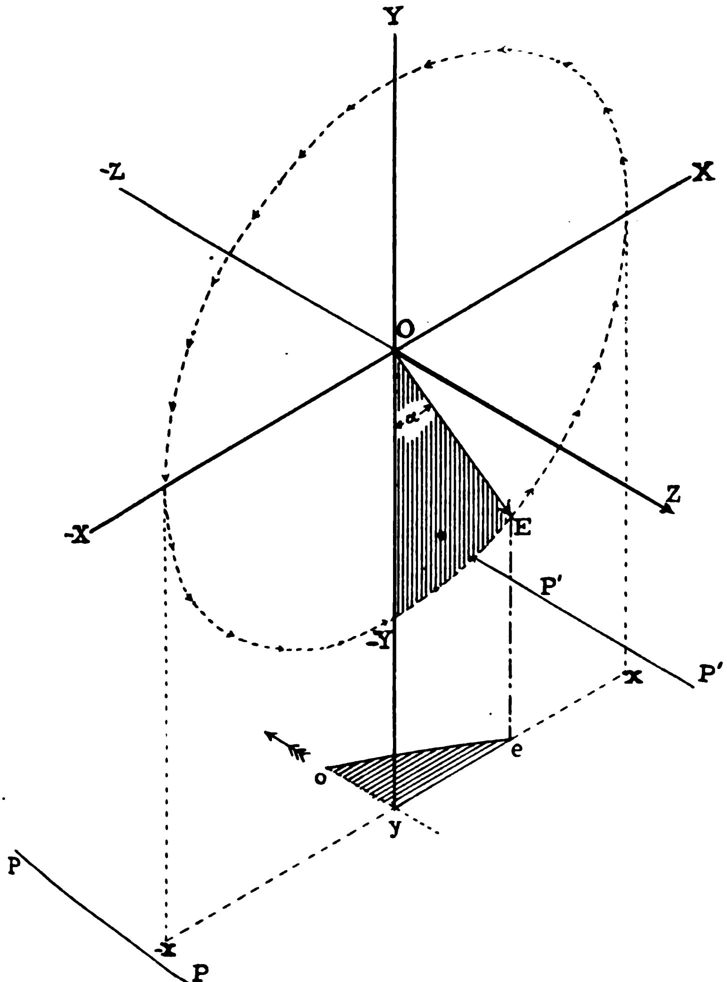

FIG. 1.—Rotative vector and sinusoidal projection. Isometric projection. $X\,O\,Y$ plane of rotation, $P\,P\,P'\,P'$ plane of projection.

scale of volts per cm., the maximum cyclic value of a certain sinusoidal e.m.f., say the e.m.f. generated harmonically in the secondary winding of a particular transformer. The direction of rotation may be positive, as indicated by the orbital arrows.

If the frequency of the voltage in the transformer is n cycles per second; then we know that the angular velocity of rotation must be $\omega = 2\pi n$ radians per second. Moreover, the vector $O\,E$ must, of course, coincide with $O\,X$ when the generated voltage attains its maximum positive value.

The circular orbital motion of the end E of the rotation vector will then correspond to the vector equation:

$$O\,E = E_0\,\epsilon^{j\omega t} \qquad \text{volt-scale cm. } \angle \qquad (1)$$

where t is the time, in seconds, from the start at a particular axis such as $O\,X$, ϵ is 2.71828..., the base of Naperian logarithms, $j = \sqrt{-1}$, and E_0 is the maximum cyclic value of the e.m.f. to a voltage scale of length. Equation **(1)** is sometimes written:

$$O\,E = E_0\,cis\,(\omega t) \qquad \text{volt-scale cm. } \angle \qquad (2)$$

We shall represent either of the above expressions by the briefer and more convenient notation:

$$O\,E = E_0\,\underline{/\omega t} \qquad \text{volt-scale cm. } \angle \qquad (3)$$

where the quantity ωt within the angle sign $\angle$ means that the angular distance of the radius vector $O\,E$ from the initial reference axis is ωt radians, or degrees, according to the unit of angle adopted.

As is well known, the orthogonal projection of the radius vector $O\,E$ upon the plane of reference $P\,P$, $P'\,P'$, which is parallel to the plane $O\,X\,Y$, performs a simple harmonic motion. If the reference axis of starting, at time $t = 0$, is $O\ -Y$, then at any instant, t seconds thereafter, the distance $y\,e$, or projection of $O\,E$, will be:

$$\overline{y\,e} = E_0 \sin \omega t = E_0 \sin \alpha \qquad \text{volt-scale cm.} \qquad (4)$$

which will correspond to the e.m.f. generated at that instant in the transformer.

Again, if the reference axis of starting, at time $t = 0$, is $O\,X$, then at any time t:

$$\overline{y\,e} = E_0 \cos \omega t = E_0 \cos \alpha \qquad \text{volt-scale cm.} \qquad (5)$$

If the plane of projection $P\,P\,P'\,P'$ be moved parallel to itself in the direction shown by the arrow at o; or, if with the plane

of projection at rest, the coördinate system of axes moves in the direction $O\,Z$, with uniform linear velocity, then, as is well known, the projecting point will trace out a sinusoid $o\,e$ having amplitude ordinates $o\,x$, and time abscissas $o\,y$.

Relation of Phase to the Direction of Rotation

Convention No. 1. If we employ two co-frequent rotative vectors, such as $O\,E$ and $O\,I$, Fig. 2, representing say an im-

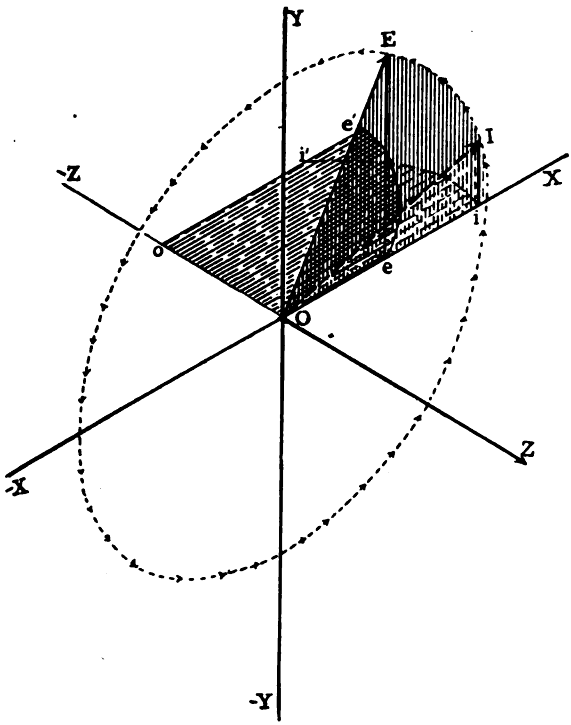

Fig. 2.—Pair of rotative vectors of the same frequency and their cosinusoidal projections. Representation direct. Current lagging. Isometric projection. $X\,O\,Y$ plane of rotation. $X\,O\,Z$ plane of projection.

pressed e.m.f., to a certain volt-scale, in a simple alternating-current circuit, and the current strength thereby produced in the same circuit, to a certain ampere-scale; then, if there is inductive reactance in the circuit, we know that the current will lag behind the impressed e.m.f. This means that the orthogonal projection of $O\,I$ on the axis $O\,X$ of reference, must reach its maximum after $O\,E$ has passed its maximum projection on that

axis. Consequently, with the plane $X\,O\,Z$, fixed in space, and with the vectors $O\,E$, $O\,I$, rotating in the positive direction, as shown by the orbital arrows, $O\,I$ must make a negative angle with $O\,E$; or, $O\,E$ must make a positive angle with $O\,I$; so that the angle $E\,O\,I$ is trigonometrically ***negative***, as shown in Fig. 2. If the vector $O\,E$ starts from the position $O\,X$, at time $t = 0$, the orthogonal projection of $O\,I\ \underline{/\omega t - \theta}$ proceeds to execute on the axis $O\,X$ the cosinusoid:

$$O\,i = I_0 \cos(\omega t - \theta) \qquad \text{ampere-scale cm.} \quad \textbf{(6)}$$

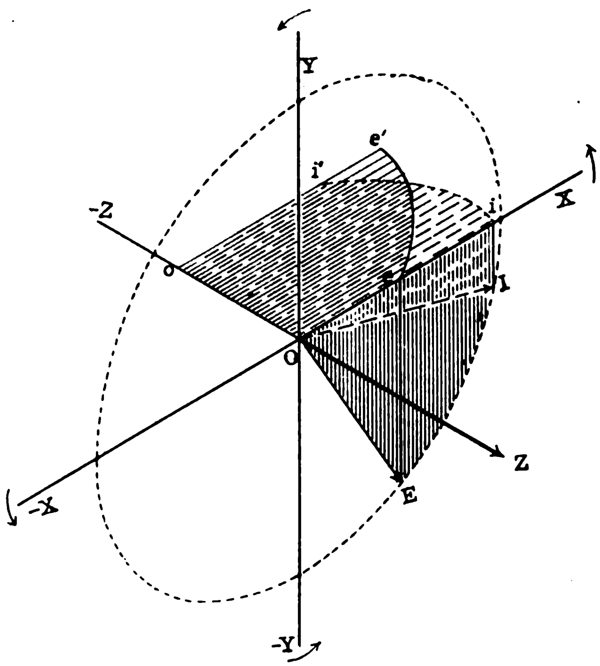

FIG. 3.—Pair of rotative vectors of the same frequency and their cosinusoidal projections. Representation inverse. Current lagging. Isometric projection. $X\,O\,Y$ plane of rotation. $X\,O\,Z$ plane of rotation.

If the origin O and system of axes advance uniformly with respect to the stationary plane of projection $X\,O\,Z$ in the direction $O\,Z$; or, what is equivalent, if the plane of projection moves in the direction $O\,Z$ past a fixed origin O, the cosinusoids $e'\,e$ and $i'\,i$ will be traced as curves with amplitude ordinates, and times as abscissas. This convention was adopted in alternating-current technology by Fleming in 1887.[1]

1. Fleming, loc. cit.

Convention No. 2. If, however, we reverse the direction of rotation of the vectors $O\,E$, $O\,I$ in their orbit; *i.e.*, if we adopt negative rotation, we shall require that the leading vector make a negative angle with the lagging vector, a condition opposite to that above defined.[2] Or, keeping the direction of rotation positive, we may assume that the vectors are fixed in their plane; but that the plane of projection rotates positively at the uniform angular velocity ω. Thus in Fig. 3, the two vectors $O\,E$ and $O\,I$ may respectively represent, as before, the impressed e.m.f. and the current in an inductively reactive circuit. If these two vectors remain fixed; but the axis $-X\,O\,X$, and with it the plane of projection $Z\,O\,X$, rotates in the positive direction, of the curved arrows, about the $O\,Z$ axis, the e.m.f. vector $O\,E$ must make a negative angle with the lagging current vector $O\,I$; or the pair will take relatively opposite positions to those they had in Fig. 2, and the angle $E\,O\,I$ will be *positive*.

Convention No. 3. Some writers, instead of employing rotative vectors to be projected orthogonally upon an axis of reference, prefer to represent simple harmonic motion by the device of an *intercepting circle*.[3] Thus, in Fig. 4, the heavy circle $O\,G\,E\,F$, in the plane $X\,O\,Y$, may be regarded as stationary in space, and the axis $O\,R$, sometimes called a "time-axis," rotates positively in this plane about the origin O, as shown by the curved arrows, with uniform angular velocity ω radians per second, or n revolutions per second, commencing at the position $O\;-Y$, when $t = 0$. As the axis $O\,R$ advances, it becomes intercepted by the circle $O\,G\,E$, and forms to that circle a chord of increasing length, until it reaches the position occupied in the Figure by $-X\,O\,X$, when the chord will have become a diameter, and the length of the moving axis intercepted by the fixed circle will be a maximum in the positive direction. As the rotation of $O\,R$ about O continues, the length intercepted by the circle will diminish, until it will be zero in the position $O\,Y$. Continuing the rotation, we may adopt either of two equivalent conventions, between which writers are divided. We may either use a second circle, shown in dotted lines at $O\,g\,e\,f$, equal and opposite to the first, and consider this to be a negative circle, such that all intercepts upon

2. Gisbert Kapp, "Alternate-Current Machinery", Fig. 7, Proc. Civil Engineers, London, 1889, reprinted in Van Nostrand Science Series, New York, 1889, p. 27.

3. Kapp, loc. cit., Fig. 8.

C. P. Steinmetz, "Alternating-Current Phenomena", 1897.

$O R$ shall be considered negative, intercepts on $O r$ being ignored; or, we may dispense with the second circle, and allow intercepts on $O r$ to count as negative intercepts, during the second half of the revolution. In either case, the length of the intercept on the moving axis will follow a simple harmonic law, according to the expression $O E \sin \omega t$ units of length, $O E$ being the diameter of the intercepting circle.

If the rotating axis starts, at time $t = 0$, from the position $-X O X$ in Fig. 4, the length intercepted by the fixed circle will likewise follow a simple harmonic law according to the expression $O E \cos \omega t$.

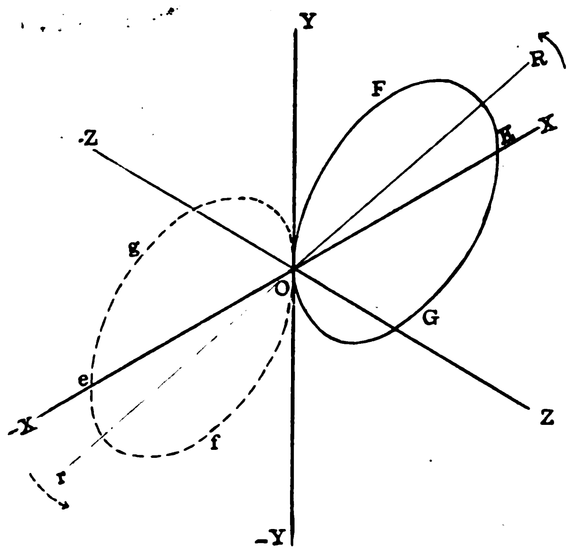

Fig. 4.—Uniformly rotating vector and fixed intercepting circle, with simple harmonic intercept. Isometric projection. $X O Y$ plane of rotation.

In order to represent the relation between a simple harmonic current in an inductively reactive circuit under a simple harmonic e.m.f. by convention 3, two intercepting circles are required, as in Fig. 5. Here the negative counterparts are omitted, and negative intercepts are assumed with each circle. As shown in the figure, it is necessary, with the positive direction of rotation of the moving axis $O R$, to have the diameter of the circle $O I$ make a positive angle with the diameter of the circle $O E$, in order that the intercept on the current circle shall reach its maximum later than the intercept on the voltage circle. A lagging current, therefore, requires a *positive* angle $E O I$.

In the practical use of convention 3, the circles are commonly omitted, for convenience, and are merely represented by their diameters $O E$ and $O I$, which become respectively the stationary-vector e.m.f. and current of the diagram.

As regards the use or disuse of the negative circle, as in Fig. 4, it is simpler to dispense with it, and to use negative intercepts on $O Y$, except when the positive and negative waves are not symmetrical. In that case, the retention of the negative loop simplifies the diagram, since it avoids superposition of loops, and ambiguity of paths.

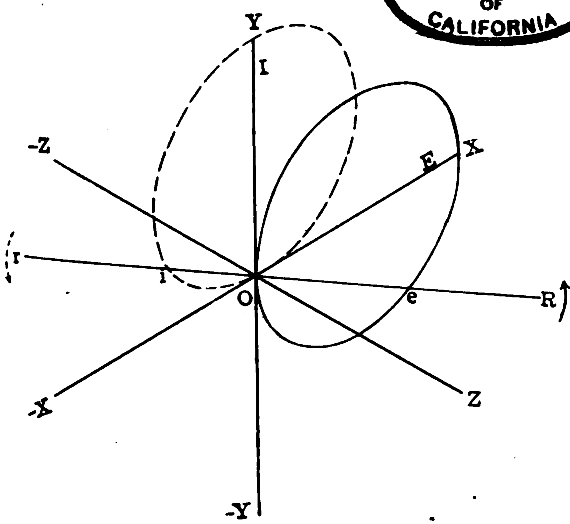

FIG. 5.—Pair of intercepting circles representing a simple harmonic e.m.f. and a simple harmonic current lagging 90 deg. behind the same. Isometric projection. $X O Y$ plane of rotation. Representation inverse.

Convention No. 4. If we assume that the axes of Fig. 5 are fixed in space, but that the intercepting circles $O E$ and $O I$ rotate together in the positive direction about the center O, measuring off from moment to moment intercepts on some axis, say $O X$, equal to the respective instantaneous voltage and current; then in order to represent an e.m.f. and a lagging current, it will be necessary for the diameter of $O E$ to make a positive angle $I O E$ with the diameter of $O I$, or the angle $E O I$ will be *negative*, the opposite condition to that in Fig. 5. According

then to convention 4, Fig. 5 would represent a current $O\,I$ leading the e.m.f. $O\,E$ by 90 degrees.[1]

Convention No. 4 does not seem to be in use, but is introduced here in order to complete the classification symmetrically, see Table II.

TABLE II

Conventions Employed in Rotative - Vector Diagrams

Convention: Type	Convention: No.	Direction of rotation	Plane of projection	Vectors	Intercepting circles	Vector	Angle $E\,O\,I$ for an inductive circuit	User	Date of use	Expression of inductive impedance	Representation
Orthogonal projection or clock diagram	1	+	Fixed	Rotating			−	Fleming Blakesley	1887 1889	$r+jx$	Direct
		−	Rotating	Fixed			−	...		$r+jx$	
	2	+	Rotating	Fixed			+	...		$r-jx$	Inverse
		−	Fixed	Rotating			+	Kapp	1889	$r-jx$	
Polar coördinates or Intercepting circles	3	+			Fixed	Rotating	+	Kapp Steinmetz	1889 1893	$r-jx$	Inverse
		−			Rotating	Fixed	+	...		$r-jx$	
	4	+			Rotating	Fixed	−	...		$r+jx$	Direct
		−			Fixed	Rotating	−	...		$r+jx$	

Representation of Complex Harmonic Quantities

It has been claimed that a complex harmonic quantity is only capable of being represented as a closed curve to polar coördinates by the method of the intercepting curve, and that the projecting curve, or "clock-diagram", cannot be used in

1. The above four conventions by no means exhaust the possibilities of rotative-vector representation. For example, as a subtype of interceptive or polar representation, we might assume the two circles $O\,E$, $O\,I$ of Fig. 5 to have their diameters on one and the same line, instead of being angularly displaced. Two angularly rotating displaced vectors could then be employed for e.m.f. and current intercepts respectively, instead of the single rotating vector $O\,R$. With such an arrangement, a lagging vector current $O\,I$ would make a negative angle with the e.m.f. vector $O\,E$, or would reverse the relations of Fig. 5. That is, it would produce direct representation. Since, however, this method does not seem to have been used, it is omitted from the Classified Table of Conventions.

such cases.[1] It is true that the simple projecting-circle or clock-diagram, with uniform angular velocity of the radius vector, cannot represent a non-sinusoidal or complex harmonic wave; just as it is true that the simple intercepting circle, with uniform angular velocity of the radius vector, cannot represent a complex harmonic wave. But in the same manner that a change in the

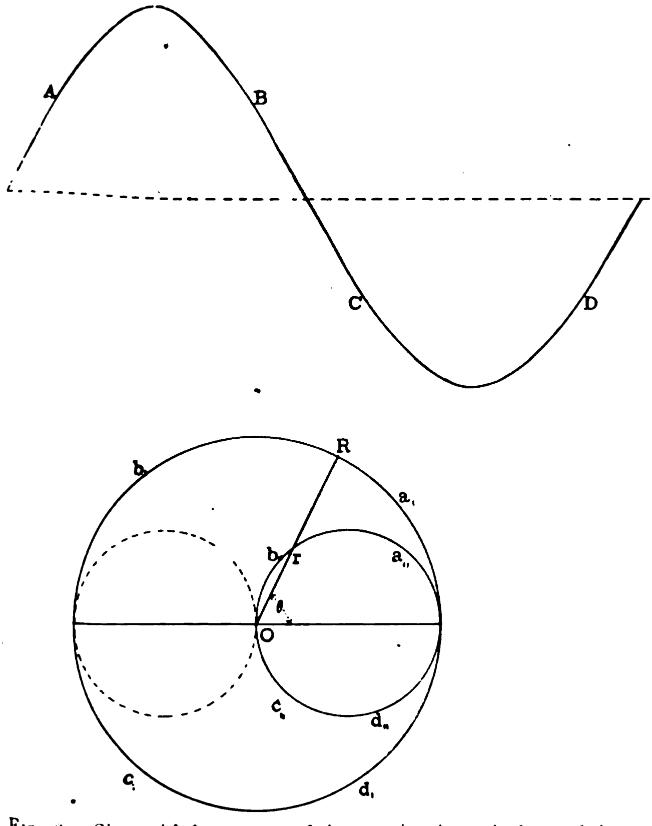

FIG. 6.—Sinusoidal wave and its projecting circle and its intercepting circle.

form of intercepting curve will permit of any complex wave being presented in polar coördinates, so a corresponding change in the form of the projecting curve will permit of the same result. Thus in Fig. 6, the sinusoid *A B C D*, drawn to rectangular coördinates, may be represented either by the projecting circle

1. Alternating-Current Phenomena, by C. P. Steinmetz, 4th Edition, 1908, p. 44.

$a_\prime\ b_\prime\ c_\prime\ d_\prime$, or by the intercepting circle $a_{\prime\prime}\ b_{\prime\prime}\ c_{\prime\prime}\ d_{\prime\prime}$, with or without its dotted neighbor. Similarly, in Fig. 7, the triangular wave $A\ B\ C\ D$, drawn to rectangular co-ordinates, may be represented either by the projecting curve $a_\prime\ b_\prime\ c_\prime\ d_\prime$, or by the intercepting curve $a_{\prime\prime}\ b_{\prime\prime}\ r\ O$, with or without its dotted neighbor. The relation between corresponding radii on the polar curves is always:

$$\bar{O}\,r = \bar{O}\,R\cos\theta \qquad \text{cm.} \quad (7)$$

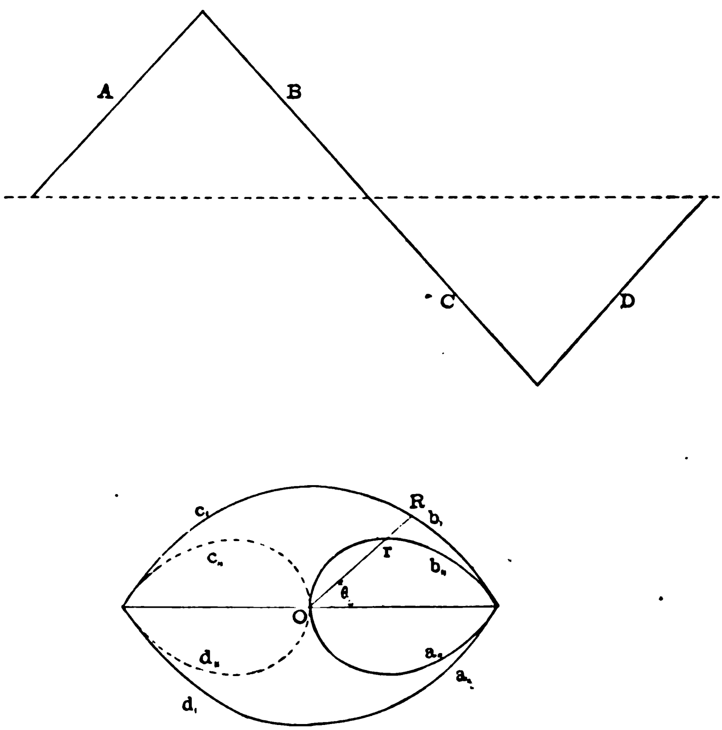

FIG. 7.—Triangular wave, its projecting curve, and its intercepting curve.

where $\bar{O}\,r$ is the radius vector (Figs. 6 and 7) of the intersecting curve, at the angle θ with the initial line of reference, and $\bar{O}\,R$ is the corresponding radius vector of the projecting curve. Consequently, having given either the polar projecting curve, or the polar intercepting curve of any complex harmonic alternating-current wave, the other can be immediately deduced.

It will be evident from the above considerations that with a pair of rotative vectors (Fig. 8) in the plane $X\ O\ Y$, one $O\ E$

representing an impressed e.m.f., and the other $O\,I$ the resulting current, in a simple alternating-current circuit, the question as to whether $O\,I$ is to be interpreted as a leading or a lagging current does not depend upon the use of projecting as against intercepting curves. It may be either a leading or a lagging current with either the "clock" diagram (Fig. 1) or the "spectacles" diagram (Fig. 4). It depends entirely upon the convention employed. If, with a projecting curve, the two vectors of Fig. 8 rotate (in the positive direction) as in convention No. 1, then $O\,I$ represents a lagging current. If on the contrary, the vectors are to be considered as stationary, and the axis of refer-

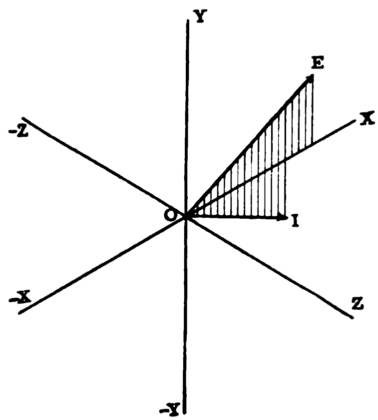

FIG. 8.—Vector e.m.f. and current in simple alternating-current circuit. The current is either a leading or a lagging current according to which convention used in vector representation. Isometric projection. $X\,O\,Y$ plane of rotation.

ence rotates positively with respect to them, as in convention No. 2, then $O\,I$ represents a leading current. Again, if with a fixed intersecting axis $O\,X$, a pair of circles located with their rotating diameters on $O\,E$ and $O\,I$, the vectors of Fig. 8 rotate in the positive direction, as in convention No. 4, $O\,I$ represents a lagging current. Finally, if the vectors $O\,E$ and $O\,I$ are fixed, and represent the diameters of fixed intersecting circles, with respect to which an axis of reference rotates positively, as in convention No. 3, $O\,I$ represents a leading current.

Aside from mental habit and psychological inertia, any one of these conventions appears to be as good as another. If the positive direction of rotation is understood in all cases, each con-

vention appears to be logical and systematic. It cannot be maintained that one or more are right and the rest are wrong. The question is essentially one of arbitrary convention, not of demonstration. Nevertheless, it is very important that the matter should be settled definitely by general agreement.[1] Much ambiguity results from the present dissension; because it is often difficult to ascertain, when opening a text-book in order to consult it, which method of representation the author follows. Imagine the confusion which would ensue in the worlds of pure and applied mathematics, if it were left to the choice of each writer to select which direction of the axis $-X\ O\ X$ Fig. 8, say, should be positive; so that some books should be written on the assumption of $O\ X$, Fig. 8, being plus, and others on the basis of $O\ X$ being minus. Or again, suppose it were left open to individual selection, which direction of rotation in a plane, clockwise, or counter-clockwise, should be taken as positive. These arbitrary selections have long been fixed by universal agreement among mathematicians. Yet this is the kind of dissension which exists to-day in the world of vector alternating-current technology.[1]

Moreover, it is not enough that the decision should be made and accepted nationally. The only satisfactory decision must be made and accepted internationally.

Direct and Inverse Representation

In what follows, this paper will conform to what seems the majority of opinion on this matter, and $O\ I$ in Figs. 8 and 10, will be regarded as a lagging current with respect to the e.m.f. $O\ E$. This means adhering to conventions 1 and 4, and by preference to convention 1. This method of representation which, in the direction of positive rotation, makes a *leading* current *lead*, and a *lagging* current *lag*, with respect to its e.m.f., will be called, for the purposes of distinction, *direct representation*, and the opposite method, involving either convention 2 or convention 3, will be called *inverse representation*.

Tables III and IV contain lists, which are by no means exhaustive, of publications using direct and inverse representations

1. The urgent need for the standardization of alternating-current vector rotation has been pointed out by various writers, both in this country and in Europe. See W. S. Franklin: A discussion of some points in Alternating-Current Theory. TRANSACTIONS A.I.E.E., May 1903, Vol. 21, pp. 589–601, and Carl Richter, Alternating-current Diagrams, Elek. u. Maschinenbau, July 12, 1908, pp. 608, 609.

respectively. No attempt has been made to discover more publications using one method than the other, and in the search that led to the formulation of these lists, no publications which contained vector diagrams were discarded, except such as made it difficult to decide which method was followed. The fact that 42 publications appear in the list of direct representation and 24 in the list of inverse representation, indicates a distinct preponderance in favor of direct representation. The dissension is not confined to any single country, or group of countries, and it dates as far back as 1889 at least.

TABLE III

Publications Employing Direct Representation of Alternating-Current Vectors

Name of publication	Author	Publisher	Date
1. Conductors for Electrical Distribution.	F. A. C. Perrine	D. Van Nostrand, N. Y.	1907
2. Electrical Engineer's Pocket Book	H. A. Foster	"	1908
3. Alternating-Current Machines.	Sheldon, Mason and Hausmann	"	1909
4. Standard Handbook for Electrical Engineers		McGraw Pub. Co., N. Y.	1908
5. Munroe & Jamieson's Pocket Book		Ch. Griffin & Co., London	1908
6. Direct and Alternating Current Testing	F. Bedell	D. Van Nostrand, N. Y.	1909
7. Elements of Electrical Engineering	Franklin & Esty	MacMillan Co.	1909
8. Electric Waves	W. S. Franklin	"	1909
9. Standard Polyphase Systems	M. A. Oudin	D. Van.Nostrand	1909
10. The A. C. Transformer	F. G. Baum	McGraw Pub. Co.	1903
11. Electric Power Transmission	L. Bell	"	1907
12. Problems in Electrical Engineering	W. V. Lyon	"	1908
13. Electrical Engineering Leaflets	Houston & Kennelly	The Elec. Engineer	1897
14. A Laboratory Manual of Physics and App El	E. L. Nichols	MacMillan Co.	1894
15. Alternating Currents	Bedell & Crehore	W. J. Johnston Co.	1893
16. Alternating Currents	D. C. & J. P. Jackson	MacMillan Co.	1896
17. Electrical Transmission of Energy	A. V. Abbott	D. Van Nostrand	1904
18. Alternating-Current Motors	A. S. McAllister	McGraw Pub. Co.	1907
19. The Elements of Alternating Currents	Franklin & Williamson	MacMillan Co.	1901
20. Alternating-Current Machinery	W. Esty	Am. Sch. Corresp.	1909
21. Electrical Measurements	Carhart & Patterson	Allyn & Bacon	1895
22. A Text Book of Electrical Machinery	Ryan, Norris and Hoxie	John Wiley	1903
23. The Principles of A. C. Working	A. Hay	Biggs & Co.	1897
24. Telephone Lines and their Properties	W. J. Hopkins	Longmans Green	1894
25. Experimental Electrical Engineering	V. Karapetoff	John Wiley	1908
26. Electrical Problems	Hooper & Wells	Ginn & Co.	1902
27. The Dynamo	Hawkins & Wallis	MacMillan Co.	1909
28. Electricity and Magnetism	F. E. Nipher	J. L. Boland Co.	1895

	Name of publication	Author	Publisher	Date
29.	Alternating Currents	C. G. Lamb	Ed. Arnold, London	1906
30.	Lecons d'Electrotechnique Générale	P. Janet	Gauthier-Villars	1908
31.	Pratique Industrielle des Courants Alt:	G. Chevrier	Carré & Naud	1900
32.	Recherche Elémentaire des Relations:	O. de Bast	Léon de Thier	1899
33.	Distribution de l'Energie par Courants Polyphases	J. Rodet	Gauthier-Villars	1903
34.	La Technique de la Houille Blanche	E. Pacoret	Dunod et Pinat	1908
35.	Moteurs Synchrones	A. Blondel	Gauthier-Villars	—
36.	Die Wissenschaftlichen Grundlagen der Elek:	G. Benischke	J. Springer	1907
37.	Fernleitung von Wechselströmen	G. Roessler	J. Springer	1905
38.	Handbuch der Elektrischen Beleuchtung	Herzog & Feldmann	"	1907
39.	Messungen an Elektrischen Maschinen	R. Krause	"	1907
40.	Ein-und Mehrphasen W: Erzeuger	F. Niethammer	Hirzel	1900
41.	Der Drehstrom	J. Krämer	H. Costenoble	1896
42.	La Tecnica delle Correnti Alternate	G. Sartori	Ulrico Hoepli	1903

TABLE IV

PUBLICATIONS EMPLOYING INVERSE REPRESENTATION OF ALTERNATING-CURRENT VECTORS

	Name of Publication	Author	Publisher	Date
1.	Dynamo-Electric Machinery	S. P. Thompson	Spon & Chamberlain	1905
2.	Elements of Electrical Engineering	C. P. Steinmetz	El. W. & Engr.	1902
3.	Electrical Energy	E. J. Berg	McGraw Pub. Co.	1908
4.	Whittaker's El. Engr's. Pocket Book		Whittaker & Co.	1906
5.	Electrical Engineering	Thomälin	Longmans Green	1907
6.	Electrical Engineering	Rosenberg, Gee & Kinzbrunner	John Wiley	1908
7.	The Induction Motor	B. A. Behrend	El. W. & Engr.	1901
8.	Transformers	Gisbert Kapp	Whittaker & Co.	1908
9.	Vectors and Vector Diagrams	Cramp & Smith	Longmans Green	1909
10.	Alternating-Current Engineering	E. B. Raymond	D. Van Nostrand	1907
11.	Polyphase Currents	A. Still	Whittaker & Co.	1906
12.	Practical Calculation of Transmission Lines	L. W. Rosenthal	McGraw Pub. Co.	1909
13.	Electrical & Magnetic Calculations	A. A. Atkinson	D. Van Nostrand	1903
14.	Laboratory & Factory Tests in El: Engg:	Sever & Townsend	"	1907
15.	Electricity and Magnetism	Foster & Atkinson	Longmans Green	1896
16.	Electric Motors	H. M. Hobart	Whittaker & Co.	1904
17.	Single-phase Commutator Motors.	F. Punga	"	1906
18.	Essais des Machines	Duquesne et Rouviére	Béranger	—
19.	Stromverteilungssysteme	P. Häfner	Jänecke	1906
20.	Untersuchung elektrischer Systeme.	H. Hausrath	J. Springer	1907
21.	Der Drehstrommotor	J. Heubach	J. Springer	1903
22.	Die Wechselstromtechnik	E. Arnold	"	1902
23.	Ruhende Umformer	V. Bondi	Jänecke	1908
24.	Impianti Elettrici a Correnti Alternate	A. Marro	V. Hoepli	1907

Example of a Non-rotative Vector

A simple example of a non-rotative vector is an ordinary impedance of the type $z\,\underline{/\theta}$ ohms, as indicated in Fig. 9. An ordinary impedance does not pass through zero cyclically, like an alternating e.m.f. or current, and no practical use is at present derivable from the notion of rotating a vector impedance about its origin. In direct representation, the impedance of Fig. 9 is essentially an inductive impedance, as distinguished from a condensive impedance. That is, it represents the impedance of some particular reactance coil. With inverse representation, however, it would necessarily represent a condensive impedance, or the impedance of some particular condenser, operated at a certain frequency, in series with a certain resistance.

Impedances, admittances, reluctances and permeances, when treated as vectors, are essentially non-rotative vectors.

Quantitatively, the application of a non-rotative vector to a rotative vector as a multiplying factor alters both the magnitude and the phase of the resultant rotative vector, without altering the frequency or angular velocity of rotation. Thus the relation:

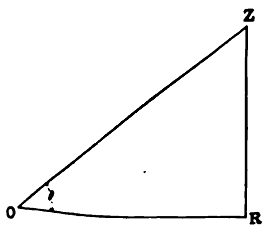

Fig. 9.—Non-rotative vector inductive impedance. Direct representation.

$$I\,\underline{/\omega t} \times Z\,\underline{/\theta} = I\,Z\,\underline{/\omega t + \theta} \quad \text{volts } \underline{/} \qquad (8)$$

indicates that the product of a vector current I amperes, rotating with the angular velocity ω radians per second, and a vector impedance of Z ohms, with the fixed angle θ radians, gives rise to a vector voltage $I\,Z$, rotating with the same angular velocity as I, but advanced θ radians in phase beyond I. The orthogonal projection of the voltage product will follow a simple harmonic motion, θ radians advanced in phase with respect to the corresponding motion of I.

Degradation of a Rotative Vector into a Stationary Vector

It frequently happens that a quantity which is capable of being regarded as a rotative-vector quantity, needs only to be designated as a vector in respect of phase relation to another vector or vectors; as, for example, when a simple harmonic alternating current, of say 10 amperes r.m.s., is desired to be designated as a vector lagging, perhaps 37 degrees in phase, behind a simple

harmonic impressed e.m.f. of 100 volts r.m.s. It would be possible to give a direct representation of this condition as in Fig 2 with a rotative vector OE of 141.4 volt-scale length, followed at 37 deg. by a rotative vector OI of 14.14 ampere-scale length. But if there is no necessity for drawing attention to the orthogonally projective properties of these vectors, they may be represented as a simple non-rotative pair, OE, OI, Fig. 10, in which case it is convenient to use their virtual or root-mean-square values, instead of their maximum values. We may consider that, quantitatively, this diagram represents the following conditions:

$$OE = OI\,/\underline{0^\circ} \times Z\,/\underline{37^\circ} \qquad \text{volt-scale cm.}\ /\underline{\ \ } \qquad \textbf{(9)}$$

and

$$OI = OE\,/\underline{0^\circ} \div Z\,/\underline{37^\circ} \qquad \text{ampere-scale cm.}\ /\underline{\ \ } \qquad \textbf{(10)}$$

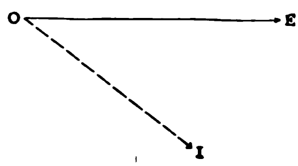

FIG. 10.—E.m.f. and lagging current. Stationary vectors.

That is, there is some non-rotative vector impedance of $10\,/\underline{37^\circ}$ ohms which connects, by Ohm's law, a virtual e.m.f. of 100 volts with a virtual current of 10 amperes lagging 37 deg. behind it.

In general, therefore, a non-rotative vector operator, such as an impedance, multiplied into a rotative vector, produces a rotative vector of changed amplitude and phase, but when multiplied either into a pure non-rotative vector, or into a stationary vector, produces a non-rotating vector of changed amplitude and phase, according to the property of multiplication of complex numbers:

$$a/\underline{\alpha} \times b/\underline{\beta} = ab/\underline{\alpha+\beta} \qquad \text{numeric}\ /\underline{\ \ } \qquad \textbf{(11)}$$

Power in Simple Alternating-Current Circuits

It is well known that if a simple harmonic e.m.f. $E_0 \cos \omega t$ volts, where E_0 is the maximum cyclic value, propels a simple harmonic current $I_0 \cos(\omega t \pm \theta)$ amperes; so that the e.m.f. and current differ in phase by the positive or negative angle θ, the electric power developed in the circuit by the source of e.m.f. on the current is at any instant:

$$p_t = \frac{E_0 I_0}{2}\{\cos\theta + \cos(2\omega t \pm \theta)\} \qquad \text{watts} \qquad \textbf{(12)}$$

$$= EI\{\cos\theta + \cos(2\omega t \pm \theta)\} \qquad \text{"} \qquad \textbf{(13)}$$

where E and I are respectively the virtual or root-mean-square e.m.f. and current; or if P be the product $E\,I$, of root-mean-square volts and amperes:

$$p_t = P\left\{\cos\theta + \cos\left(2\omega t \pm \theta\right)\right\} \qquad \text{watts} \quad (\mathbf{14})$$

Consequently, any projective or interceptive rotating vector which represents the power in a simple alternating-current circuit must possess an angular velocity double that of the e.m.f. or

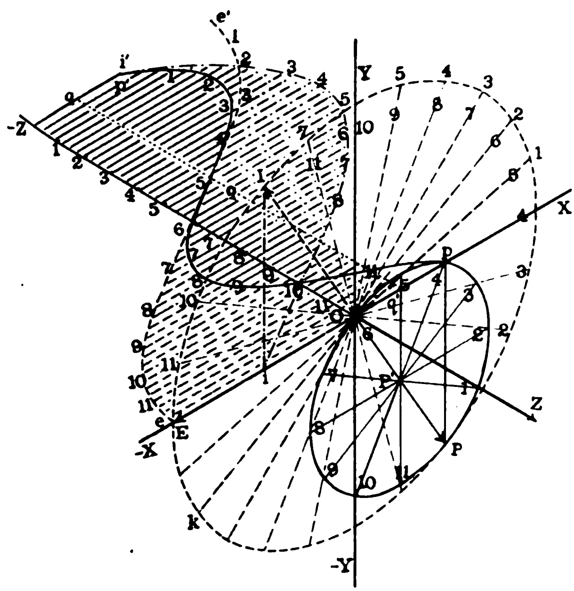

FIG. 11.—Rotative vector e.m.f. and current in inductively impedant circuit with double-frequency rotative vector power. Power factor 0.5. Isometric projection. Direct representation. $X\,O\,Y$ plane of rotation, $X\,O\,Z$ plane of projection.

current. Moreover the origin or axis of the rotating vector power must be displaced from the origin of the e.m.f. and current components.

It has been pointed out by Mr. J. Irving Brewer[1] that a construction which satisfies the rotative-vector power relations is to lay off $O\,E$, the maximum cyclic e.m.f., along the $O\,X$ axis, (Fig. 11) and $O\,I$ at the proper phase angle; in the case presented,

1. " Electrical World " Jan. 21, 1909, Vol. 53, No. 4, pp. 217–218. Inverse Notation.

$X O P$. Then on $O P$ at a point P', such that $O P' = E I$, to watt-scale, is the center of the rotating power vector which starts with doubled angular velocity from the position $P' P$, at the moment when E_0 starts from $O X$, and I_0 from $O P$.

Under these conditions, the three rotating vectors will project on the fixed axis $-X O X$, and on the moving plane $X O Z$, the respective instantaneous values of power, e.m.f. and current.

Non-rotative Vector Power

If a simple harmonic current of I root-mean-square amperes flows through an alternating-current circuit of impedance $R+jX = Z\,\underline{/\alpha}$ ohms, ($A C$, Fig. 12), the root-mean-square potential-difference E volts on the circuit will be obtained by the operation:

$$E\,\underline{/\alpha} = I/0 \times Z/\alpha = IZ/\alpha \qquad \text{root-mean-square volts} \,\underline{/\ } \qquad (15)$$

Here I is taken either as an ordinary real number, or as a plane vector number of zero angle, and therefore at standard phase. That is, I is taken as a stationary vector, so that E is also a stationary vector e.m.f., ($D F$ Fig. 12), advanced in phase α radians or degrees ahead of the current. The real component $D E$, is the effective root-mean-square component of potential difference, so far as concerns the average liberation of power from the source into the circuit, and the imaginary component $E F = j I X$, is the reactive root-mean-square component potential-difference, or the component which develops reactive power on the current. This reactive power is directed from source to circuit, and back again, in one power cycle, or in one half-cycle of current.

Again, if we multiply the non-rotative vector p.d. $D F$ by the stationary, vector current, according to the formula:

$$P\,\underline{/\alpha} = I\,\underline{/0} \times E/\alpha = I\,E\,\underline{/\alpha} = E\,I/\alpha \qquad \text{watts}\,\underline{/\ } \qquad (16)$$

we obtain a stationary vector power G K, advanced α degrees or radians ahead of the current. This power is the apparent power, commonly called volt-amperes. It is perhaps practically advantageous to call the unit of apparent power the volt-ampere in order to distinguish apparent power from effective power in engineering; but a volt-ampere is essentially a watt, and the apparent power is correctly stated as apparent or resultant watts,

the vector sum of effective and reactive watts[1]. The effective component $G\,H$ is the average power delivered to the circuit by the generator, and is usually called the "real power". The reactive power $H\ K$ is, however, when considered from within the circuit, just as real as the effective power $G\,H$; so that the term "real power" is unsuitable. The reactive power $H\,K$ is the maximum cyclic power expended in transmitting energy into and out of the magnetic flux linked with the circuit, being alternately plus and minus, or from and to the generator, in successive quarter cycles of current. This energy is kept in the circuit; whereas the effective power $H\,G$ transmits energy out of the circuit. The maximum reactive cyclic power $H\,K$ is all internal. The effective power $G\,H$ is the average of that delivered externally, is the cyclic average of the instantaneous total internal power, and is also the maximum cyclic value of the externally delivered power.

Finally, if we divide the stationary vector power by $2\,\omega$ according to the equation:

$$W/\alpha = P/\alpha \ / \ (2\omega) \qquad \text{joules per energy cycle} \ / \qquad (17)$$

we obtain the stationary energy vector $L\,N$. This is the maximum cyclic apparent, or resultant oscillatory, energy delivered by the generator to the circuit in each energy cycle, over and above the average effective energy delivered at the rate $G\,H$. The perpendicular component $M\,N$ is the maximum cyclic change of reactive energy in the magnetic flux of the circuit. The horizontal component $L\,M$ is the maximum cyclic oscillation of effective energy.

A practical example will illustrate the above conditions. We may assume a large single-phase 60-cycle alternator delivering at its switchboard eight megawatts (8,000 kw.) of effective power, and three megawatts of reactive power, or 8.544 apparent megawatts, under a power factor of 0.936. If the delivered current is 4,000 amperes, its terminal voltage will be 2,136 volts.

The stationary-vector power diagram for this generator is shown at $G\,H\,K$ in Fig. 12. The analysis of the circuit conditions is given in Fig. 13, to rectangular coördinates and to

1. A useful diagram of this type—essentially a stationary-vector power diagram—appears at page 540 of Mr. Percy H. Thomas' paper on "Calculation of the High-Tension Line". PROCEEDINGS of A.I.E.E., June, 1909.

sinusoidal current phase. The current I has a maximum cyclic strength of $4000\sqrt{2}$, or 5,656 amperes. The potential difference E is ahead of the current by $\alpha = 20.6$ deg. It is analyzed into the effective component ($D\,E$ Fig. 12) of 2,000 volts root-mean-square, or $E_f = 2{,}828$ volts maximum (Fig. 13),

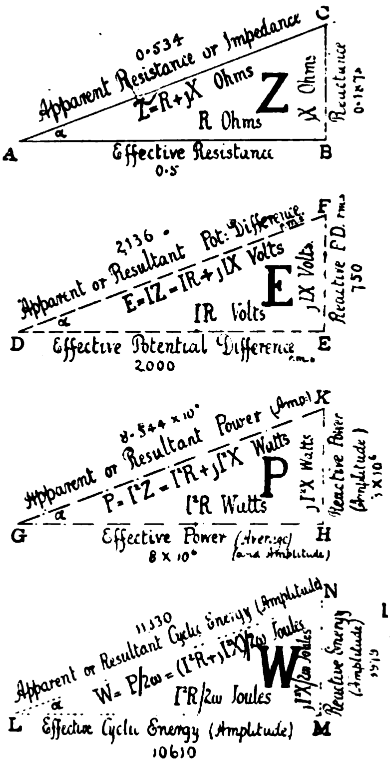

FIG. 12.—Stationary vector diagrams of impedance, potential-difference, power and cyclic energy in an alternating-current circuit to phase of current as standard.

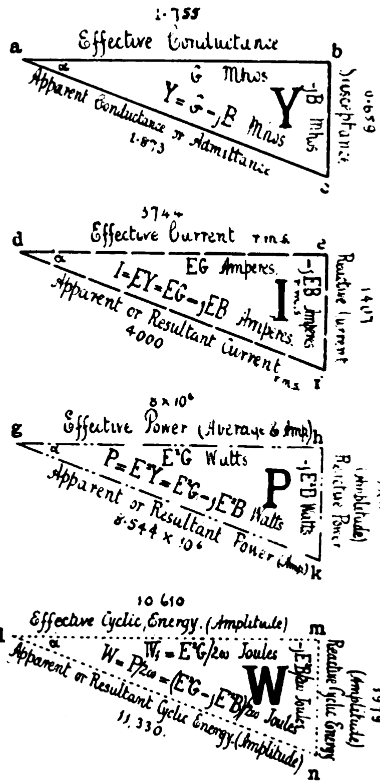

FIG. 14.—Stationary vector diagrams of admittance, current, power and cyclic energy in an alternating-current circuit to phase of potential-difference as standard.

and the reactive component $E\,F$ of 750 volts root-mean-square ($E_k = 1061$ volts maximum). The product $I\,E_f$ produces the effective power P_f of eight megawatts amplitude, ($G\,H$ Fig. 12) above and below the average P_m of eight megawatts. The product $I\,E_k$ produces the reactive power P_k of three megawatts

amplitude ($H K$ Fig. 12). The sum of these two quadrature power components is the total apparent power $I E = P$ of 8.544 megawatts above and below the mean P_m.

The reactive power P_k is associated with a cyclic energy change of $W_k = 0.3979$ myriajoule $= 3{,}979$ joules $= 405.6$ kilogram-meters or 2940 ft-lb. This energy ($M N$ Fig. 15) is stored

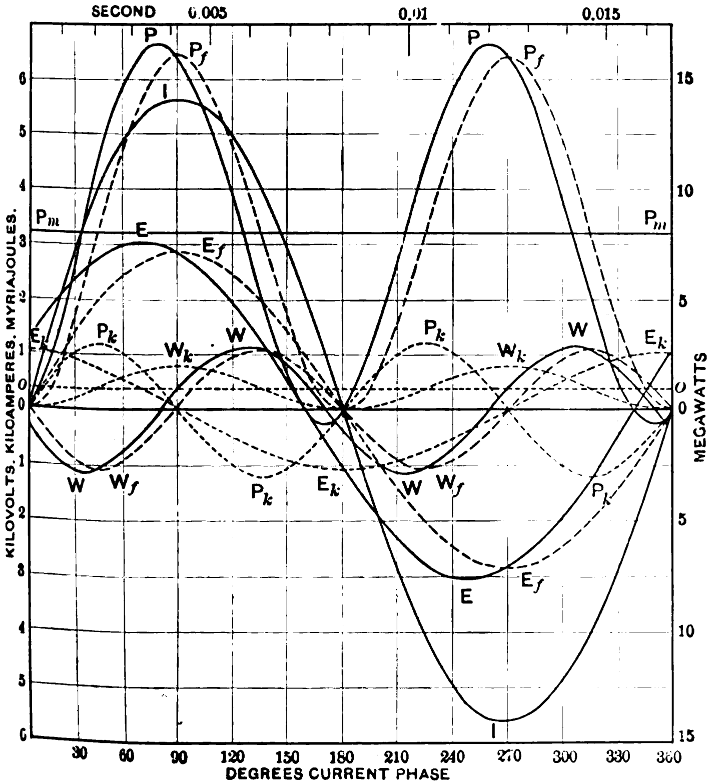

FIG. 13.—Analysis of potential-difference, power and energy to current as standard of phase.

in, or removed from, the magnetic flux of the circuit in one quarter of an energy-cycle, or one eighth of a current-cycle (0.00208 second) over and above a steady stock of energy $o\ o$ (Fig. 13) of equal amount. The total magnetic energy in a current half-cycle is therefore:

$$2 W_k = I^2 X/\omega \qquad \text{joules per cycle of current} \qquad \textbf{(18)}$$

or 7958 joules (0.7958 myriajoule), at 90 deg. and at 270 deg. of current-phase.

The effective power P_f is associated with a cyclic energy change of W_f = 1.061 myriajoule in each cycle ($L\ M$ Fig. 12) above and below the average of eight megajoules per second, or 13.333 myriajoules per current cycle, delivered by the generator outside of the circuit.

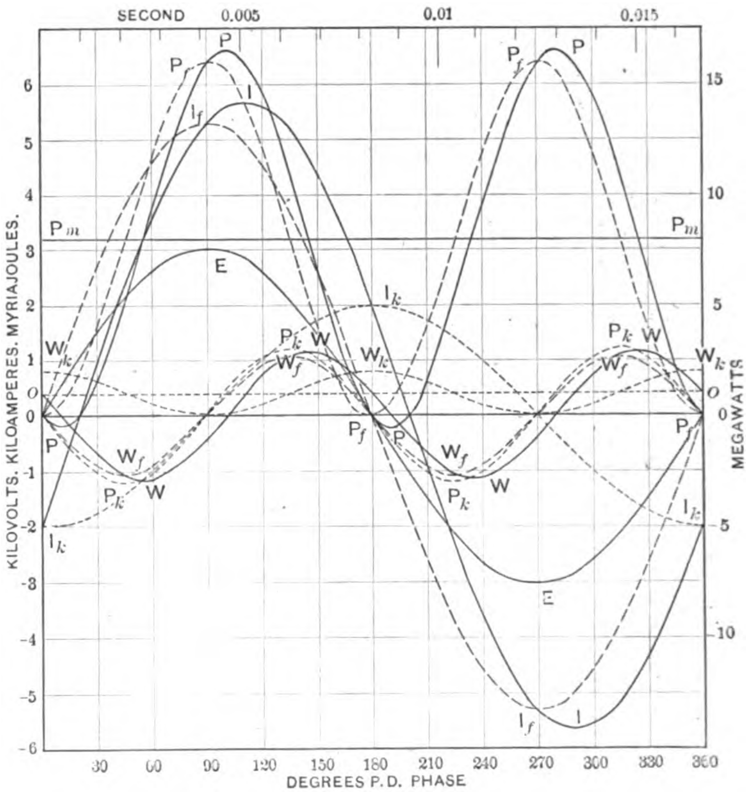

FIG. 15.—Analysis of current, power and energy to potential-difference as standard of phase.

The total cyclic energy change is W = 1.133 myriajoule ($L\ N$ Fig. 15) above and below the average of 6.667 myriajoules per energy cycle.

Fig. 12 contains, therefore, a non-rotative impedance triangle $A\ B\ C$ of ohms, a stationary potential-difference triangle $D\ E\ F$ of root-mean-square volts, a stationary power triangle $G\ H\ K$ of

maximum cyclic or amplitude watts, and a stationary energy triangle $L\,M\,N$ of maximum cyclic or amplitude joules. These four non-rotating vector triangles pertain to every alternating-current circuit, considered with reference to the stationary vector current $I/\underline{0}$ root-mean-square amperes. If the circuit contains condensance, instead of inductive reactance, the four triangles will all be inverted, with negative reactive quantities, or of the geometrical type indicated in Fig. 14. If the current and p. d. in the circuit are sinusoidal, then all of the 18 vector quantities involved will be strictly interpretable by simple harmonic theory. If the current, or the potential-difference, or both, are only approximately sinusoidal, the vector triangles may still be computed, and they permit of being considered as " equivalent sinusoidal " triangles.[1] In this case, however, the various vector quantities cease to be strictly interpretable physically. Finally, if the current or potential-difference, or both, depart widely from the sinusoidal type, the vector triangles, although still existing logically and geometrically, may fail completely to be interpreted physically. That is, the vector impedance, voltage, power and energy may be inconsistent with the physical conditions. In such cases, it is necessary to analyze the current and potential-difference into harmonic components, develop a series of vector triangles, one for each component, and aggregate the separate effects.[2]

If in a single-frequency (simple harmonic) circuit, the impedance triangle be given and the root-mean-square current, the other three vector triangles of E, P and W, follow immediately, and without any ambiguity. That is, the stationary-vector series Z, E, P and W is unique. But if either the power or energy triangle be given initially, the Z triangle which follows therefrom is ambiguous, because there may be condensance associated with the reactance, either in series or parallel, and a doubly infinite system of circuits could therefore be devised that would satisfy the W, P, and E vectors. The only definite conclusion in such a case is that the reactance preponderates over the condensance to the amount indicated by the X of the Z triangle.

If one or more impressed counter-electromotive forces exists in

1. Steinmetz, " The Law of Hysteresis ", TRANSACTIONS A.I.E.E., May, 1894, Vol. 11, pp. 570, 616.

2. Steinmetz, " Symbolic Representation of General Alternating Waves and of Double-Frequency Vector Products ", TRANSACTIONS A.I.E.E., June, 1899. Vol. 16, pp. 269–304.

the circuit, as, for example, that of a synchronous alternating-current motor, the Z diagram that follows from a given P diagram and current I, is logically consistent, and may be practically useful, but is purely fictitious.

If instead of taking the phase of the current as standard, we take the phase of the potential-difference as standard, we exchange $E/\underline{0}$ for $I/\underline{0}$ as the fundamental stationary vector, and we obtain the four stationary vectors Y, I, P, and W of Fig. 14, connected by the relations:

$$I \,\overline{\diagdown}\, \alpha = E/\underline{0} \,.\, Y \,\overline{\diagdown}\, \alpha \qquad \text{root-mean-square amperes } \underline{/\ } \qquad \mathbf{(19)}$$

$$P \,\overline{\diagdown}\, \alpha = E/\underline{0} \,.\, I \,\overline{\diagdown}\, \alpha \qquad \text{max. cyclic watts } \underline{/\ } \qquad \mathbf{(20)}$$

$$W \,\overline{\diagdown}\, \alpha = (P \,\overline{\diagdown}\, \alpha)/(2\,\omega) \qquad \text{max. cyclic joules } \underline{/\ } \qquad \mathbf{(21)}$$

It will be observed that the P and W triangles in Fig. 14 are inverted by comparison with those in Fig. 12, and yet the same single-phase alternator is supposed to be operating on the same circuit in each case. The anomaly is explained by the fact that as shown by Figs. 13 and 15, the resultant power curve P lies intermediate in phase between the current curve I and the potential-difference curve E, so that while the power is leading with respect to the current, it is lagging with respect to the potential-difference. Consequently, the stationary power vector of an alternating-current circuit has, with direct representation, either a negative or a positive angle, according as the phase of one or other of the two quantities E and I is taken as standard, as well as whether the circuit is reactive or condensive.

By comparing Figs. 13 and 15, it will be seen that the curves E, I, P and W, or resultant potential-difference, current, power and energy, all correspond, or may be superposed each on each; but the components E_f, E_k, I_f, I_k, P_f, P_k and W_f, W_k lie on reversed sides of their respective resultants in the two figures, as called for by the two sets of stationary-vector diagrams in Figs. 12 and 14.

It follows therefore that the P and W stationary-vector diagrams exist in two mutually inverted forms for every single-frequency alternating-current circuit; whereas the E, I, Z and Y stationary-vector diagrams are single, their position (erect or inverted), depending upon whether the circuit is inductively or

condensively reactant, as well as upon whether direct or inverse representation is employed.

Rotative Properties of the Stationary Vectors E, I, P, and W

In Fig. 12 the vector $E = I Z$ is taken as stationary; but it is of course capable also of being considered as a rotative vector, rotating about the vertex D, with the angular velocity ω. In that case, the three voltages E, E_f and E_k should each be increased in the ratio of $\sqrt{2}$, or should be changed in scale, in order

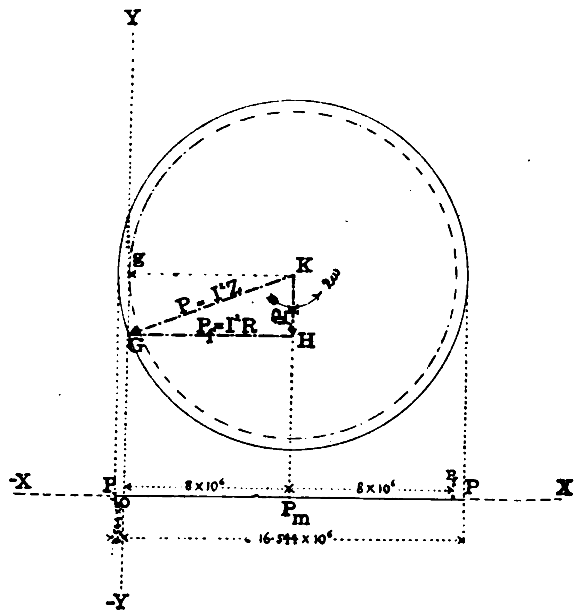

Fig. 16.—Rotative vector power diagram for current standard phase.

that their orthogonal projections on a stationary reference axis, or interceptions on a stationary circle, should correspond to the several instantaneous voltages of impressed potential-difference, effective potential-difference and reactive potential-difference.

In Fig. 12 the power vector $P = I^2 Z$ is also taken as stationary; but it is capable of being considered as a rotative vector without any change of scale, by rotating the triangle $G H K$, about the vertex K, with the positive angular velocity 2ω. This is represented in Fig. 16, where K is the center of rotation

in the plane $X\ O\ Y$ of the paper, $K\ g = H\ G$, and the extreme left-hand projection of g is taken at o, as the origin of power coördinates, in the plane $X\ O\ Z$ of projection. The projection of K, at P_m, then marks off the steady average power of the system in watts, while the projection points $P\ P$, marking the limits of the rotating vector $I^2\ Z$, indicate the range of cyclic oscillation of the power. Thus, as shown in Fig. 13, the power pulsates between -0.544 and $+16.544$ megawatts once in each power-cycle, or half current-cycle. Similarly, the rotating vector $K\ H$ projects, with respect to the center P_m, the instantaneous magnitude of the reactive power P_k about the zero line $O\ O$, Fig. 13. In accordance with Fig. 13, the rotation of Fig. 16 is assumed to start at a moment when the vector current I, rotating with angular velocity, ω, if applied with its center on K, would occupy the direction $K\ H$.

Similarly, if we rotate the power triangle in Fig. 14 about its vertex k, with the angular velocity $2\ \omega$, we shall obtain the same diagram as Fig. 16, except that the phase order of advance will be reversed; *i.e.*, P_f, followed by P and P_k, instead of P_k followed by P, and P_f. The orthogonal projections of these three vectors will then correspond to the curves P_f, P and P_k as given in Fig. 15 to potential-difference phase.

In Fig. 12, the energy vector $W = I^2\ Z/(2\omega)$ is also taken as stationary; but it is capable of being considered as a rotative vector without any change of scale, by rotating the triangle $L\ M\ N$ about the vertex N with the positive angular velocity $2\ \omega$, and taking instantaneous projections—not on the $X\ X$ axis—but on the $Y\ Y$ axis, as shown in Fig. 17. Here the successive rotating vectors, W_k, W, and W_f project the sinusoidal curves W_k, W, and W_f of Fig. 13, each with respect to its own zero line. At the moment represented in Fig. 17, the current I is supposed to start with angular velocity ω from the position $N\ M$, with center N, and to project orthogonally on the $X\ X$ axis.

Similarly, if we rotate the stationary energy triangle $l\ m\ n$ of Fig. 14, about the vertex n, with positive angular velocity $2\ \omega$, and project upon the $Y\ Y$ axis, we shall obtain a diagram like that of Fig. 17, except that the order of vector succession will be reversed, in accordance with the projected curves of Fig. 15.

But the rotating energy vector of Fig. 17 only projects the fluctuation of energy in the circuit. There is, in addition to this fluctuation of energy, a steady stream of energy delivered from the circuit, corresponding to the steady average power

$O P_m$ of Figs. 13, 15 and 16. If we represent the steady energy stream by the straight line $O P_m$ in Fig. 18, which shows 8 myriajoules in 0.01 second, or at the rate of 8 megajoules per second, then the resultant oscillation of energy, by Figs. 12, 13, 14, 15, and 16, is the sinusoidal curve $W W$, completing two cycles in 1/60th of a second. Superposing the fluctuation on the steady stream, we obtain the broken wavy line a, b, c, d, of energy delivered from the generator against time, or current phase, as abscissas. It will be seen that, between 150 and 200 degrees of phase, the energy flow halts, and slightly reverses. At this time, and at corresponding times in successive energy cycles, the

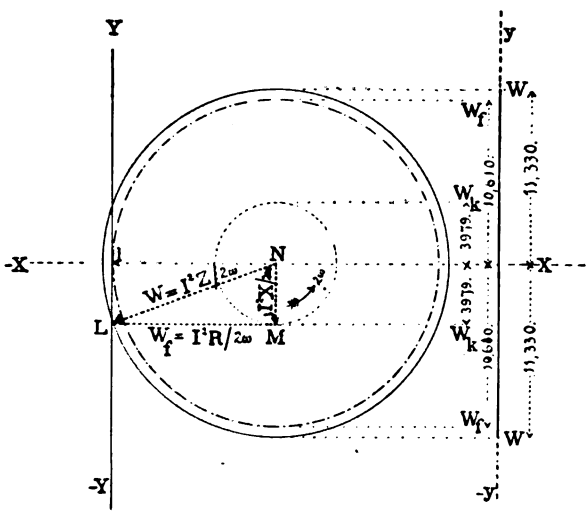

FIG. 17.—Rotative-vector energy diagram for current standard phase.

energy ceases to flow from the generator to the circuit; but ebbs back from the circuit to the generator.

The above state of energy affairs may be represented projectively by imparting to the center of the uniformly rotating energy vector $N L$ or $n l$ (Fig. 17), a uniform velocity of translation of P_m joules per second in the direction of the Y axis. But this is equivalent to mounting the energy vector on a wheel whose axis is at N (Fig. 19), the rotation being on the X Y plane. The tread radius of the wheel is made equal to W_f, to joules scale, the flange radius of the wheel is made equal to W, to joules scale. A point on the flange is then allowed to project orthogonally on the Y Y axis, as the wheel rolls on the Y Y rail at the angular

velocity 2ω radians per second. The path of the moving flange point L, on the $X\ Y$ plane, will be an oblate trochoid as shown, and the projection of the point, at 24 successive equal time intervals during the motion, is indicated on the line $y\ y$. It will be seen that the trochoid forms a small recedent loop at the end of its curve, and while the tracing point describes this loop, the

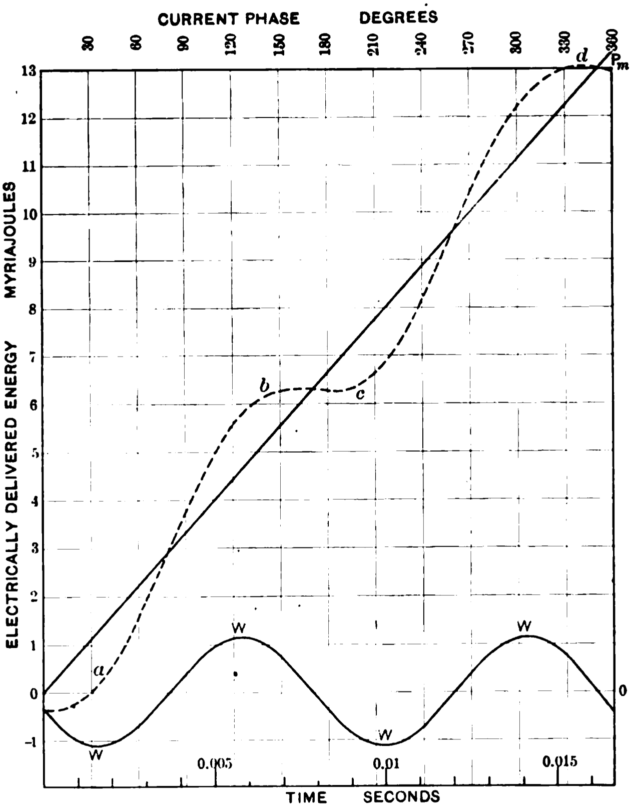

FIG. 18.—Energy-time diagram of alternating-current generator.

energy projection-point undergoes a small recession. If the tracing plane $Y\ O\ Z$ should move uniformly in the direction $O\ -Z$ during the motion, the trace could be made to correspond to the curve a, b, c, d, of Fig. 18.

If the circuit, instead of being inductively reactive with a power-factor of 0.936, should be non-inductive (with power-factor 1.0), the flange on the rolling wheel disappears. The

tracing point then lies on the tread of the wheel. As shown in Fig. 20, the tracing point describes a cycloid in the $X\ O\ Y$ plane, and the recessional loops in the tracing path disappear. The energy delivered by the generator to the circuit then halts at each cycle of energy vector rotation, or turn of the wheel; but it does not reverse.

If, on the contrary, the impedance factor Z/R of the circuit increases, either inductively or condensively, the flange radius bears the same proportion to the tread radius. The oblate

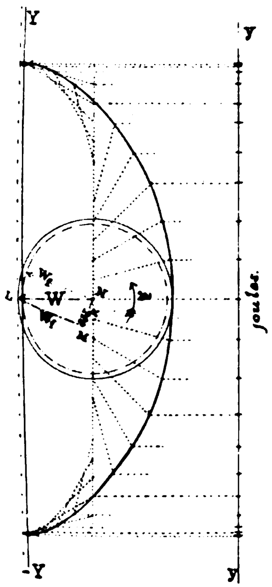

FIG. 19.—Projection energy of rotative- and rolling-vector energy triangle.

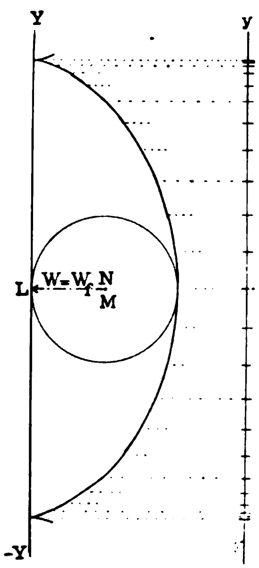

FIG. 20.—Rotating- and rolling-vector energy for non-inductive circuit.

trochoid described, as in Fig. 21, by the tracing point on the flange, develops larger recessional loops to the left of the line $Y\ Y$, with more marked reversals of motion and energy in the projected point.

Analytically, if W be the flange radius, and W_f the tread radius of the rolling wheel, the distance of the projected point along $y\ y$ from the initial position at which W lies parallel to the $-X\ X$ axis is:

$$w_t = W_f\, 2\omega t + W \sin 2\omega t \qquad \text{joule-scale cm.} \qquad \textbf{(22)}$$

or substituting for W_f and W their values $P_f/2\omega$ and $P/2\omega$ respectively,

$$w_t = P_f t + \frac{P}{2\,\omega} \sin 2\omega t \qquad \text{joules} \qquad \mathbf{(23)}$$

$$\therefore \quad p_t = \frac{d\,w_t}{dt} = P_f + P \cos 2\omega t \qquad \text{watts} \qquad \mathbf{(24)}$$

as already deduced from Figs. 13 and 15.

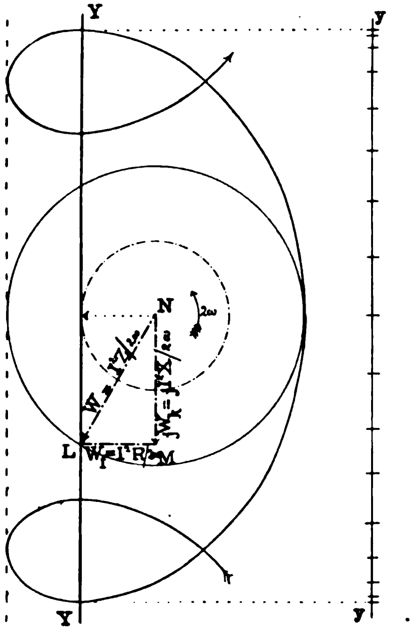

Fig. 21.—Rotative- and rolling-vector energy triangle for circuit of power factor 0.5.

Finally, if the circuit be purely reactive, or resistanceless, the tread radius becomes zero, and the wheel spins without rolling. The path of the tracing point on the flange is then a pure circle. Its projection on the $Y\ Y$ axis is a simple harmonic motion, and on the $Y\ O\ Z$ plane, a pure sinusoid.

Consequently, with suitable convention as to direction and sign of translatory motion, the energy given to an alternating current circuit may be represented by the vertically falling shadow, on the horizontal supporting rail, of a point on the flange of a uniformly rolling wheel. The rate of motion of this shadow will be

the power given to the circuit. The average power will be represented by the uniform speed of the axle. The instantaneous power by the instantaneous velocity of the shadow. If a second wheel be geared with the axle so as to rotate in the same direction with half the angular velocity, suitably selected radii on the latter wheel will represent the p. d. and current in the circuit, the instantaneous projections of these radii being measured on a vertical coördinate axis, and not on the horizontal rail.

Conformity of the Algebra of the Alternating-circuit and Continuous-current Circuits

Finally, it should be pointed out that just as, in regard to impedances, admittances, currents, and e.m.fs., the algebra of the single-frequency alternating-current circuit is the same as the algebra of the continuous-current circuit, the former dealing with complex quantities while the latter deals with real quantities;[1] so the algebra of both circuits is the same, or at least may be regarded as the same, in dealing with power. For the power product of an e.m.f. $E/\underline{0}$ and a current $I/\underline{\theta}$, or of an $E/\underline{\theta}$ and a current $I/\underline{0}$, is $E\,I/\underline{\theta} = I\,E/\underline{\theta}$ watts and not $E\,I \cos\theta$ watts. The average externally delivered power, as well as the average instantaneous power, is however $E\,I \cos\theta$ watts and the maximum cyclic internally-reactive power is $E\,I \sin\theta$ watts.

Summary of Conclusions

The algebra and geometry of vector alternating-current technology, as developed in text books, are, at present, in a state of great and unnecessary confusion as to direction of rotation.

The confusion has existed for more than twenty years, and is not confined to any one country or language.

Calling that representation "direct" which denotes a *leading* current as *leading*, in the order of positive rotation, some two thirds of the alternating-current text-books use direct representation, and the remaining one third inverse representation.

The existing dissension relates to conventions and not to facts.

The directions of rotation and representation should be standardized by mutual international agreement.

1. This law was first announced by the writer, restricted however to impedances and admittances, in the paper on "Impedance", Transactions A.I.E.E., April 1893, Vol. 10, pp. 175–232. The law was speedily extended by Dr. C. P. Steinmetz to cover currents and e.m.fs.

The terms "real power" and "wattless power" are inaccurate and misleading.

It is readily possible to compute and discuss the power in an alternating-current circuit as a stationary-vector quantity, without reference to the double frequency of rotative-vector power.

The power developed by any single-frequency alternating e.m.f. E root-mean-square volts on a co-frequent current $I\underline{/\pm\theta}$ root-mean-square amperes, is algebraically $E\,I\underline{/\pm\theta}$ watts. The externally liberated power is $E\,I\cos\theta$ watts, and is usually the principal consideration in power-transmission systems.

In any alternating-current circuit, or portion of the same, there are four non-rotating vectors Z, E, P, W to standard current phase, and also four Y, I, P, W, to standard potential-difference phase, all connected by ordinary vector arithmetic, and not involving double-frequency products.

The energy in a single-frequency alternating-current circuit follows the projection, upon the rail, of a flange-point on a wheel rolling along the rail with uniform angular velocity. The path of the flange-point is an oblate trochoid for reactive circuits—but is a cycloid for a non-reactive circuit.

The algebra of alternating currents may be regarded as the same as the algebra of continuous currents, for power as well as for other quantities; so that any formula relating to direct-current circuits is also a formula relating to single-frequency alternating-current circuits, when complex numbers are substituted for real numbers.

Notation Employed

a, b, Vector lengths (cm.).

α, β, θ, Vector angles, or phase angles (radians or degrees).

B Susceptance of a circuit, as a whole, or beyond a pair of points in the same (mhos).

c Capacity of a condenser (farads).

E_0, E E_f E_k, Maximum cyclic, virtual or root-mean-square, effective, and reactive e.m.f. in a circuit, or potential-difference at a pair of points in the same (volts).

e_t Instantaneous voltage or P. D. in a circuit at time t (volts).

$\varepsilon = 2.71828\ldots.$ (numeric).

G Conductance of a circuit as a whole, of beyond a pair of points in the same (mhos).

I_0, I, I_f I_k Maximum cyclic, virtual or root-mean-square, effective, and reactive current strength in a circuit (amperes).

i_t Instantaneous current strength in a circuit (amperes).

$j = \sqrt{-1}$ (quadrantal operator).

L Inductance in a circuit (henrys).

l Polar radius-vector of a complex number.

n Frequency of alternation (cycles per second).

ω Angular velocity of a rotating vector, or of an alternating quantity, (radians per second, or degrees per second).

P, P_f, P_k, Resultant, effective, and reactive maximum cyclic power in a circuit (watts).

P_m Average power in a circuit (watts).

p_t Instantaneous power in a circuit at time t (watts).

$\pi = 3.14159\ldots.$ (numeric).

R, r, Resistance in a circuit, or conductor (ohms).

T, A constant time interval (seconds).

t Elapsed time interval (seconds).

W, W_f, W_k, Resultant, effective and reactive maximum cyclic energy (joules).

w_t Instantaneous energy in a circuit (joules).

X, x, Reactance in a circuit (ohms).

Y, Admittance, or resultant conductance, in a circuit (mhos).

Z, z, Impedance, or resultant resistance in a circuit (ohms).

$X\,X$, $Y\,Y$, $Z\,Z$, Rectangular coördinate axis.

NOTE

The following paper is to be read at the 27th annual convention of the American Institute of Electrical Engineers at **Jefferson, N. H., June 27-30, 1910.** This paper is to be presented under the auspices of the High Tension Transmission Committee of the Institute. All those connected with the Institute and desiring to take part in the discussion of this paper may do so by being present at the meeting; or, if this is not possible, by sending in a written contribution.

Written contributions will be read at the meeting, time permitting, for which they are intended, either in full, in abstract, or as a part of a general statement giving a summary of the views of those taking the same position in the matter.

The principal object in getting out the paper in advance of the meeting is to enable and encourage those not in a position to attend the meetings to take part in the discussion by mail.

Contributions to the discussion of this paper should be mailed to **Ralph D. Mershon, Chairman, High Tension Transmission Committee, 60 Wall Street, New York,** so that they will be received not later than June 23, 1910.

(WHITEHEAD)

A paper to be presented at the 27th Annual Convention of the American Institute of Electrical Engineers, Jefferson, N. H., June 27-30, 1910.

THE ELECTRIC STRENGTH OF AIR

BY J. B. WHITEHEAD

Air is the commonest and most widely used of insulators. Its insulating characteristics are remarkably good; it has low specific inductive capacity, very low conductivity, and an electric strength or resistance to rupture which until recently has met all the demands of the electrical engineer. As a result of the increase in values of transmission voltage, however, and of improvements in high-voltage apparatus and line insulators, the electric strength of air has become a limiting factor in the long distance transmission of power.

Values of the electric strength of insulating materials are usually given in volts or kilovolts per centimeter. In the case of air, and probably in that of all other insulating substances, it is not possible to state a fixed value for the electric strength for standard conditions of temperature and pressure. The shape, size and separation of the terminals have an important influence on the electric strength as calculated from the break-down voltage. For example, the apparent electric strength of air in kilovolts per centimeter varies between 5.5 and 12 for needle points at distances between 75 cm. and 1 cm., and approaches 100 for corona formation at the surface of very small wires. Similarly there are discrepancies among the values derived from experiments with spheres of different diameter at various distances of separation, as well as with other forms of discharge terminals. The explanation of these discrepancies has not yet been satisfactorily given. It will ultimately be found however to involve some or all of the following facts:

The air between two terminals may be partly ruptured without a resulting discharge; such a partial rupture is always a cause of

copious ionization; this ionization is a separation of the ultimate particles of the air into positive and negative charges or gaseous ions which render the air highly conducting. Besides these there is a further peculiarity of the structure of the air in the neighborhood of conductors which results in a marked and regular dependence of the electric intensity causing ionization, on the radius of curvature of the electrode; this fact is particularly interesting in that the phenomenon occurs under a variation of dimensions 10^5 times as great as the mean free paths of the molecule and free electron in the atmosphere, and is thus apparently not directly connected with these quantities.

An example of the influence of these facts is the spark between needle points. The high value of potential gradient at the points causes break-down in their neighborhood, resulting in ionization, conductivity, and consequent change of shape of the effective terminal from a point to a sphere or other solid shape. The sphere enlarges until the intensity at or near its surface, decreasing with increasing radius, falls to a value which cannot further ionize the air, and there is then equilibrium without discharge. For spheres of a certain size and range of separation ionization is followed by an increase in electric intensity, and in this case is immediately followed by disruptive discharge.

Alexander Russell,* in a most valuable paper, has considered various types and sizes of terminal in which there can be no initial ionization without resulting discharge. He shows from the results of various investigators that if the terminals are chosen for these conditions, a constant value of about 39 kilovolts per centimeter is found for the electric strength of air. He also draws some interesting comparisons between his own results with spheres and those of Steinmetz with needle points, showing that they are in fair agreement when the facts of ionization as above described are considered. Russell's conclusions lead to very uniform results for the particular cases he examines, and by an extension of his reasoning it would appear that if we could determine the voltage of initial ionization or break-down for a given pair of terminals, and could calculate the corresponding potential gradient, we should arrive at the same value of the electric strength of air for all shapes and sizes of terminals. This is not the case however.

As is well known, the surface electric intensity at which

* A bibliography of the principal articles referred to is given at the end of the paper.

cylindrical wires begin to discharge increases markedly with decreasing diameter of wires. For wires of diameter one cm. and larger, the critical surface intensity is constant at about 40 kilovolts per cm., and this corresponds to the value found by Russell, and also to the value at which secondary ionization sets in, as determined by Thomson and others working with vacuum tubes. For wires smaller than one cm. the critical intensity increases, reaching the value 80 for a diameter 0.1 cm. The ionization theory offers no obvious explanation at this point, nor does Russell discuss the fact that the surface electric intensity for wires smaller than one cm. diameter may be raised far above 39 kilovolts per cm. without any evidence of break-down or ionization of the air. In fact it should be noted that Russell's constant value of 39 kilovolts per cm. depends on the assumption, not yet justified except by his conclusions, of a constant value of " lost volts " at the surface of separation between terminal and air. The apparent variation of the electric strength of air with the diameter of wire is a most promising problem for the experimental physicist. The suggestion by several writers that the air has greater strength near the wire than at a distance is only an unscientific statement of the fact. Undoubtedly the electric strength of the air will ultimately be found to be constant. The influences which for small wires reduce the actual intensity below the apparent value, and make necessary Russell's assumption, will be discovered and the correction factor for any type of terminal will then be available. Some further discussion in this connection will be found at the end of the paper.

The apparent values of critical surface intensity for cylindrical wires as determined by different observers differ considerably. The principal workers in this field have been Steinmetz, Scott, Ryan, H. B. Smith, Mershon and Watson. With the exception of the last named an account of the work of each has been presented to the Institute. Steinmetz, Ryan and Watson worked within the laboratory; Scott, Smith, Mershon and Watson on aerial lines. Watson worked with continuous potentials only. If all the observations be expressed in terms of critical surface intensity there is a marked difference in the results. Omitting those of Mershon the others show differences as great as 10 per cent for wires in the neighborhood of 0.3 cm. diameter, while the results of Mershon fall 33 per cent below the lowest of the others. Ryan and Watson have studied the influence of atmospheric pressure, Ryan that of temperature, and Mershon notes a

decided influence of water vapor in the air, Ryan's investigation in this direction being inconclusive. Two general methods of observing the point of initial break-down have been used; the visual appearance of corona, and the break, more or less sharp, in the curve connecting voltage and line current or line power. The first method introduces a considerable possibility of personal error. The second method necessitates the elimination of leakage, charging current, and transformer losses, which are often many times larger than the quantity sought, and its accuracy is open to some question.

Present Investigation

The primary aims of the present investigation have been the development of an accurate method of determining the electric strength of air in the neighborhood of round wires; the application of the method to clean smooth wires of various materials of diameter less than one cm.; and a study of the influence of moisture on the electric strength of air near smooth and rough wires. In addition, some interesting properties of the visual corona are described.

The Method. The new method developed permits a determination of the critical intensity or electric strength of air in the neighborhood of round wires to an accuracy within 0.5 per cent. It also permits accurate control of the temperature and moisture content of the air under observation. It makes use of the fact that electrical rupture is invariably accompanied by ionization, and that extremely minute traces of ionization may be detected by the gold leaf electroscope, one of the most sensitive instruments at our disposal.

The wire is stretched along the axis of an outer metallic cylinder, and the voltage applied between them. Air is drawn from the neighborhood of the wire under investigation and over a suitable discharge terminal connected to the gold leaf system of the electroscope *G*, Fig. 1. As soon as the ionization accompanying electrical break down occurs the electroscope discharges.

Near each end of the outer cylinder a series of small holes is drilled permitting air to be drawn through the cylinder. The electroscope terminal is placed close to the openings by which the air leaves. The electroscope retains its charge until the critical voltage is reached and then discharges rapidly. A diagram of the apparatus and auxiliaries is shown in Fig. 1. *A* is the wire accurately centered in the outer cylinder; it is supported under

tension by dry threads well beyond the ends of the cylinder which are closed by the wood and glass caps *B B*. Air is drawn through the cylinder by an exhaust fan, entering at *C* and leaving at *D*; the velocity of the air is measured at *F*. Any degree of moisture is obtained by bubbling the air through water at various temperatures, and the driest state by drawing through a large column of calcium chloride. The temperature of the air was controlled by passing it through a large coil of lead pipe immersed in a tank filled with ice or water of any desired temperature. The moisture content of the air was determined by

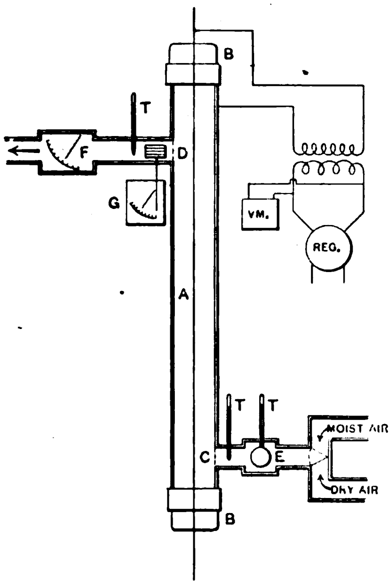

FIG. 1.—Arrangement of apparatus

reading its temperature and also the temperature of the dew point, as indicated by a polished brass mirror at *E*; water of any temperature could be passed through the solid back of this mirror, the temperature being read from a thermometer with its bulb immersed in mercury. The temperature of the air was read at each end of the tube, and by means of the coil described was varied between 6 and 40 deg. cent. The dew point could in this way be read to 0.5 deg. cent. and values of relative humidity from 0.1 up to saturation were obtained by the methods described.

The voltage was obtained from a 3-kw., 60-cycle trans-

former, 100 to 25,000 volts, the high tension winding being in four sections. The primary voltage was read on a Weston dynamometer voltmeter, standardized for this work, and was controlled by an induction regulator; for close adjustments a small amount of resistance, of negligible influence on the wave form, was inserted. The ratio of turns of the transformer as obtained from the manufacturer is 1 to 250.18 and this value is used for determining the secondary voltage. The charging current of the wire and cylinders is negligible, and no evidence of leakage current could be detected on an ammeter in the high-voltage circuit, reading to less than one tenth the normal full-load transformer current. The resistance of the primary winding affected the secondary voltage as read above by less than 0.1 per cent.

Accuracy of the Method. The electroscope was provided with a scale viewed through a telescope. Its discharge terminal was a cylindrical cage of copper wire placed within 0.5 cm. of the wall of the main outer cylinder. The reading taken was the time in seconds, as determined by a stop-watch, required for the gold leaf to pass over a fixed interval on the scale. The normal time for free leak over this interval was of the order of magnitude of a day. The eye could readily detect motion of the leaf corresponding to 250 seconds. In the experiments on clean wires an increase in the primary voltage of one per cent at the critical value was generally sufficient to reduce the time of discharge from that corresponding to its normal rate of leak, *i.e.*, thousands of seconds, to two or three seconds. These figures indicate how sharply marked is the critical voltage, and how sensitive the electroscope.

In taking observations, the electroscope is charged and a slow current of air drawn through the apparatus. With eye on the electroscope leaf the voltage is gradually raised to a value at which the electroscope just begins to discharge as detected by the eye, and its rate of leak is then measured. The voltage is increased by small steps, corresponding rates of leak being taken several times for each value. The temperature and pressure were also noted. The time for discharge drops from practically an infinite value to very low values (from two to four seconds) within a very small change of voltage. Several of the many sets of observations are given in Table III and elsewhere, and reference is made to curve 2 in Fig. 7 for the sharpness with which break-down begins. The curves are plotted between time to discharge as ordinates, and kilovolts as abscissæ.

Tests and Experiments

The first experiments described are an investigation of the influence of the velocity of the air through the apparatus. The corrections for temperature and pressure variation are then discussed. Then follow the observations on wires of various sizes, and materials under various conditions as to surface and moisture.

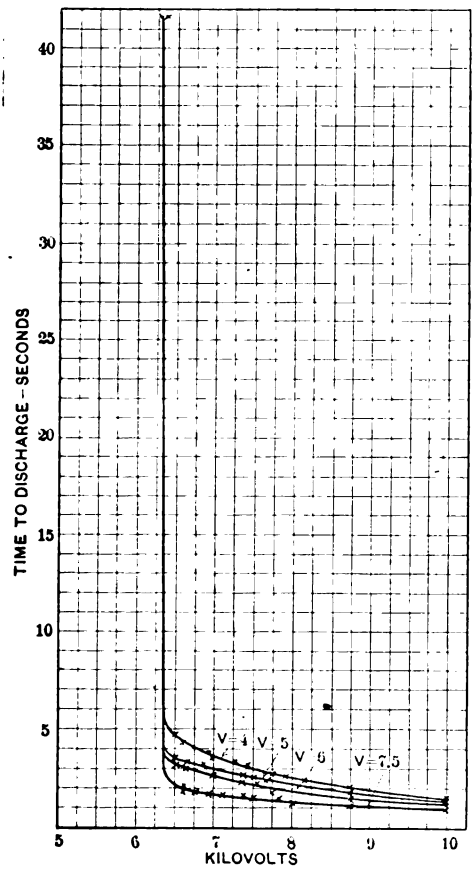

Fig. 2.—Influence of air velocity on rate of discharge

Effect of Air Velocity. A series of observations is given in Table I showing that the method as described is, within wide limits, independent of the velocity with which the air is drawn through the apparatus. A series of curves plotted from another set of observations is shown in Fig. 2. The point of initial break-down is not affected by the velocity, but the rate at which

ions reach the electroscope is. In the observations from which the curves are plotted, the electroscope was some distance from the discharging wire, permitting diffusion and recombination of the ions. The curves from the values in Table I are all superposed, since in this case the electroscope was very close to the discharging wire, and even at no motion of air in the tube the diffusion or projection of the ions from the discharging wire is of sufficient volume to discharge the electroscope so rapidly as to mask any effect of the increase by velocity.

TABLE I. CRITICAL VOLTAGE INDEPENDENT OF VELOCITY OF AIR

Velocity of air, feet per minute									
0		98		162		252		371	
Primary volts	Seconds to discharge	Primary volts	Seconds to discharge	Primary volts	Seconds to discharge	Primary volts	Seconds to discharge	Primary volts	Seconds to discharge
60.5	300	60.5	400	60.5	425	60.2	400	60.7	500
61	5	61.6	2.7	60.7	18	60.8	9	61.2	3
61.8	2.8	62.5	1	61	4.5	61.2	2.2	62	1
62.1	2	61.2	2.2	61.5	1.8	62	1.2	—	—
63.5	0.8	60.6	300	62.5	1	63	0.6	—	—

As seen, the point of initial breakdown is independent of the velocity. The action of the electroscope was found to be more pronounced when a moderate velocity is used; also a continuous draft is necessary for renewing the air, and maintaining constant conditions of temperature and moisture. Throughout the experiments a velocity of 150 ft. per min. was generally used, and the electroscope placed as close as possible to the outlet from the cylinder forming the outer terminal.

Influence of Temperature.—By means of the heating and cooling apparatus already described, the series of observations, given in Table II, were taken on polished copper wire 0.276 cm. diameter at temperatures between 6 and 41 deg. cent., Fig. 3 shows the corresponding curve corrected to 760 mm. pressure.

TABLE II. INFLUENCE OF TEMPERATURE ON CRITICAL VOLTAGE

Mean temperature, cent....	7.4	11.0	16.4	20.0	20.5	27.9	41.0
Primary volts observed....	71.6	70.7	70.5	69.1	70.2	69.0	66.8
Barometric pressure.......	763.0	755.8	764.0	755.8	765.5	765.5	765.5
Primary volts corrected to 760 mm..................	71.4	71.0	70.1	69.5	69.8	68.4	66.3

In these experiments the temperature of the air was read at the points of entering and leaving, the cylinder being covered with heat-insulating materials so as to maintain the temperature as constant as possible. The difference in temperature between the entering and leaving air was a maximum at four degrees at the highest temperature, and the mean values are given in the table. This test was undertaken to ascertain the correction factor for temperature to be applied in the later investigations. The results are not offered as being the most accurate attainable, and a more exact determination of the influence of temperature is planned for a separate investigation. The results are amply accurate for the purpose of correction, and indicate that at 760 mm. pressure there is a drop or rise of 0.22 per cent in the critical voltage for each degree centigrade rise or fall from 21

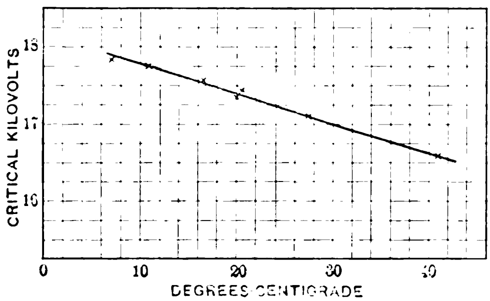

FIG. 3.—Influence of temperature –0.276 cm. wire in 6.35-cm. tube

deg. cent. Ryan has investigated the influence of temperature on the voltage at which the corona becomes visible, and his results at atmospheric pressure indicate the value 0.27 per cent per centigrade degree above or below 21 deg. cent. In the present experiments, critical voltages are reduced to 21 deg. cent. by means of the factor 0.22 per cent per degree.

Influence of Pressure. The variations in atmospheric pressure introduce considerably less disturbance than those of temperature. The minimum and maximum pressures encountered in these experiments were 750 mm. and 772 mm. Ryan and Watson have investigated the influence of pressure, but their results are not in good agreement. In these experiments, critical voltages are reduced to 760 mm. pressure by Ryan's factor. The values of this factor vary from 0.985 for 750 mm. to 1.009 at 766 mm. My observations within the narrow range stated above

are in fair agreement with these values, being 1.88 per cent variation, as against 1.53 per cent by use of Ryan's expression. As most of the observations were taken at pressures differing little from 760 mm., and necessitating corrections of only a few tenths of a per cent, no separate investigation of pressure influence was undertaken.

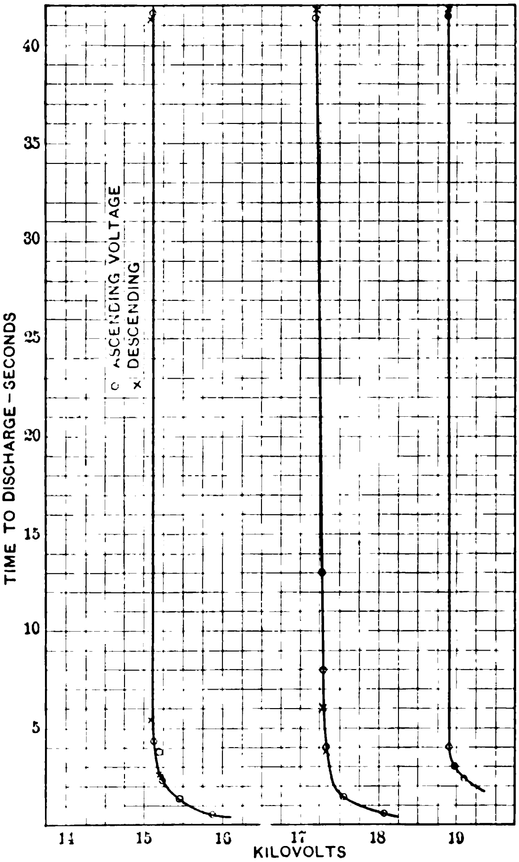

FIG. 4.—Typical curves showing critical voltage for wires of 0.205, 0.276 and 0.347 cm. diameter in 6.35-cm. tube

OBSERVATIONS ON CLEAN SOLID WIRES

A great many observations were made on copper, aluminum and steel wires of diameters between 0.089 cm. and 0.5 cm. centered in tubes of 4.9 cm., 6.35 cm. and 9.82 cm. internal diameter, and 100 cm. length. The steel wires were taken from

rods of tool steel; they were perfectly straight and readily polished and handled without danger of kinks. The copper and aluminum wires were heated by electric current to dull red and at the same time subjected to tension; they were then carefully polished and placed in the outer tube without bending or contact with other objects. The two larger tubes were placed in the vertical position and the wire held under tension in accurately centered insulating bushings on the ends. The air was strained through cotton wool and a cambric screen at the entrance to the tube. On raising the voltage the charged electroscope is unaffected until

TABLE III. POLISHED COPPER WIRES IN 6.35-CM. BRASS OUTER TUBE

0.205 cm. diam.		0.276 cm. diam.		0.276 cm. diam.	
Primary volts	Time to discharge seconds	Primary volts	Time to discharge seconds	Primary volts	Time to discharge seconds
60	∞	69	∞	68.5	∞
60.3–5	just begins	69.5–6	25	68.8	just begins
60.6	4.2	70.3	2.4 3.4 2.8 2.4	69.3	3.8 4.2
60.8	3.8 3.8 3.6	71	1.6 1.6 1.4	69.2	8 1.3 8
60.9	2.2 2.2 2.2	73.2	0.8	70	1.4 1.4 1.4 1.4
61.8	1.4 1.4	71	1.4 1.4 1.4	72.2	0.6 0.6
62.5	1 1 1	69.7–8	9.2 10	69.3	3.8
63.5	0.6	69	∞	69.2	6
61	2.2 2.4	69.2	just begins	68.7	∞
60.5	5.4	0		0	
60.2	∞	69		68.5	∞
60.3	just begins	69.6–8	9.2	68.9	just begins
				69.2	7 6
		70.3	2 2	70.1	1.4 1.4
Temperature 19 deg. cent. Barometer 764 mm. Dew point 5 deg. cent. March 4		Temperature 19.5 deg. Barometer 761 mm. Dew point 4 deg. Feb. 15 Corrected critical volts 68.8		Temperature 21 deg. Barometer 762 mm. Dew point −2.5 deg. Feb. 18 Corrected critical volts 68.7	

the critical voltage is reached when a sharply marked rapid rate of leak sets in. In Table III several sets of observations on wires of 0.205 cm. and 0.276 cm. are given; Fig. 4 gives two curves plotted from the figures of the table as well as the curve for 0.347 cm. wire. From these it may be seen that at the critical point an increase of one per cent in the voltage is sufficient to cause the electroscope to discharge in three or four seconds although it was unaffected at the lower value. With increasing values of voltage, the electroscope discharges still more rapidly, although owing to its sensibility a point is soon reached when the discharge is so rapid that its time cannot be read. The visible corona ap-

pears faintly at the beginning of the break in the curve and brightens rapidly with increasing voltage. Recalling Ryan's observations that corona and power loss begin together, this shows that there is no ionization before power loss sets in. The nature of the power loss has been the subject of much speculation, and the above fact is one leading to my conclusion that a part if not all of the loss is in the process of ionization, *i e.*, the separation of the two opposite charges on the molecules of the gas. The shape of the curve beyond the critical point depends on the air velocity, distance to the electroscope, size of its terminal etc., and it offers a means of studying the shape of the loss curve

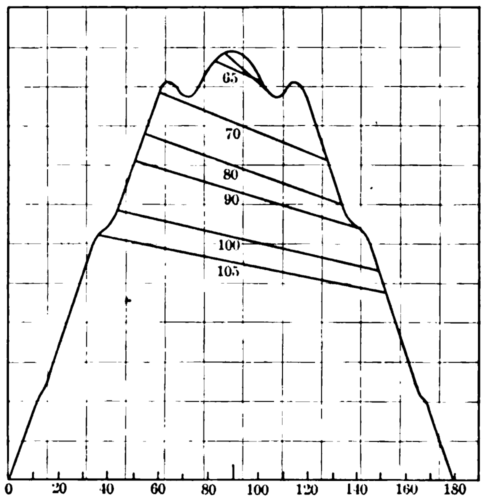

FIG. 5.—Region on voltage wave occupied by corona at various voltages

for voltage above the critical value. The investigation has not as yet been extended in this direction.

A further fact of interest in connection with these curves is that for decreasing voltage the curve is retraced, and ionization or break-down ceases at the same voltage at which it began. There is thus no apparent after-effect of foregoing ionization. This fact may be also observed by opening the transformer circuit when the electroscope is discharging; it stops instantaneously even when its initial rate is extremely rapid, *i e.*, when ionization is copious. This indicates that the life of a free ion is extremely short, and also in view of the low air velocities used that the ions

reach the electroscope by their own velocity in the electric field, rather than by any aid of the air draft. This conclusion is in accord with the independence of critical voltage and air velocity. Some further evidence in this direction is given in the description of experiments with the corona.

Table III indicates the nature of the observations taken on many variations of size and material of wire and outer tube, under various atmospheric conditions. The results on a given size of wire at different times and in different tubes are in excellent agreement when the corrections for temperature and pressure are applied. This is indicated in Table III and also in Table IV in which the results of this portion of the work are condensed. In Table IV the observed values of critical primary volts have been corrected to 21 deg. cent. and 760 mm. pressure by the factors already described. The critical value is that at which the discharge of the electroscope begins. This point is very sharply marked, and under steady circuit conditions could be read to 0.2 primary volts. On the curves of Fig. 4 it corresponds to the beginning of the steep descent of the vertical limb. The maximum electric intensity at the surface of the wire corresponding to the critical primary voltage is calculated from the primary reading by the expression

$$\frac{d\,V}{d\,x} = \frac{V}{x \log \frac{b}{a}}$$

in which V is the maximum value of potential difference between wire of radius a, and tube of inner radius b; x is the distance from the center of the wire to the point for which the calculation of intensity is made, and thus for the surface of the wire $x = a$. To obtain V, the primary voltage is multiplied by the ratio of transformation, and the ratio of maximum to effective value of e.m.f. of the 60-cycle circuit used throughout the experiments. An oscillogram of this electromotive force wave was taken, and from careful measurements of the ordinates Fig. 5 is a good reproduction. By the summation of the squares or ordinates sufficiently close together to take account of the irregularities, the ratio of maximum to effective value was found to be 1.45 for one-half wave and 1.455 for a whole wave; the value 1.452 has been used in calculating the values in the last column of Table IV.

In Fig. 6 the results given in Table IV are plotted between diameter of wire and maximum critical surface intensity. With the exception of two points, at diameters 0.276 and 0.325 cm., the curve is fairly smooth. The former point is off only 0.8 per cent and the latter for an aluminum wire about one per cent. Aluminum is very difficult to polish, the finest abrasives leaving streaks and a dull surface; this is sufficient to cause the observed lowering of critical voltage.

TABLE IV. RELATION BETWEEN DIAMETER AND CRITICAL SURFACE INTENSITY

Diam. cm.	Material of wire	Diam. of tube cm.	Material of tube	Critical primary volts corrected	Ratio	Maximum critical surface intensity
0.089	Copper	4.9	Brass	74.5	125.09	77,100
0.122	"	"	"	44.0	250.18	70,950
"	"	"	"	87.8	125.09	70,800
0.156	"	"	"	97.0	"	65,880
"	"	"	"	97.0	"	65,880
0.205	"	"	"	109.5	"	61,350
"	"	"	"	55.0	250.18	61,500
"	"	6.35	"	60.5	"	62,080
"	"	"	"	60.2	"	61,780
"	"	"	"	(8) 59.9	"	61,680
0.254	Aluminum	"	"	65.9	"	58,750
0.276	Copper	"	"	68.9	"	58,080
"	"	"	"	68.8	"	
"	"	"	"	68.5	"	
"	"	"	"	69.0	"	
"	"	"	"	(8) 68.9	"	58,080
"	"	9.52	Steel	77.3	"	57,650
0.325	Aluminum	6.35	Brass	72.8	"	55,000
0.347	Copper	6.35	"	75.13	"	54,500
0.3405	"	9.52	Steel	85.7	"	55,100
0.399	Steel	"	"	92.5	"	53,050
0.475	"	"	"	100.6	"	51,400

This curve is of interest when compared with that of Watson for continuous potentials; the curves coincide for the smallest diameters, but Watson's is lower by 6 per cent at 4 mm. If, as he states, the temperature was constant at 17 deg. cent in Watson's experiments, this suggests that a higher value of alternating potential is necessary for break-down, and that a time element is involved; an elevation of temperature however would account for a part of this difference. Ryan's values at which the corona appears are also plotted for comparison. In the present

work frequent observations of corona were made, and its appearance invariably coincided very closely with the critical voltage as indicated by the electroscope read by an independent observer.

Observations on Dirty Wire

Throughout the experiments on clean wires it was found that the least dust, dirt, or other inequality of surface was accompanied by a lowering of the critical voltage. On viewing such

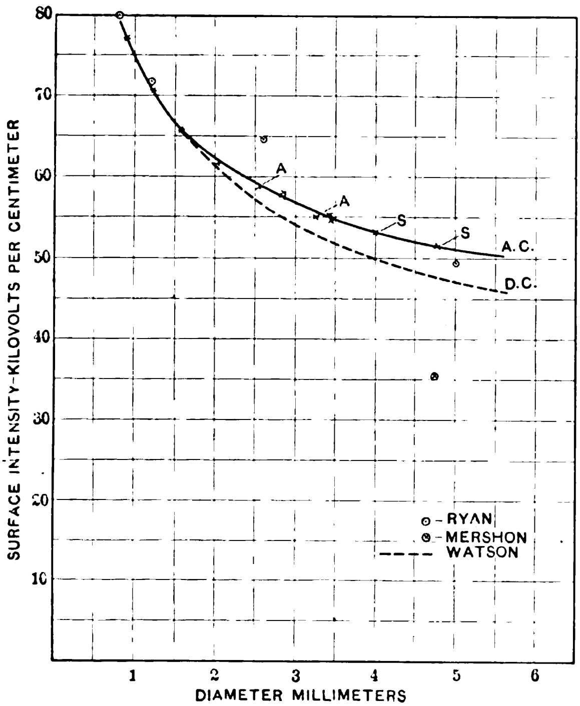

Fig. 6.—Relation of critical intensity and diameter

a wire through the end of the tube a discharging point could usually be detected. On raising the voltage, other points appear on a dirty wire, and the amount of lowering of critical voltage depends on the size and number of surface irregularities and their location with reference to the electroscope. Thus for copper wire 0.122 cm. in diameter taken from a fairly clean coil and not polished, the drop in critical voltage below that for clean wire was only one per cent. On the other hand, a 0.277-cm. polished copper wire, giving a critical surface intensity of 56,500 volts per

cm., was heated by current until it took on a flaky coat of oxide. Its critical intensity was reduced to 37,850, or by 33 per cent. Repeated observations (see Table VI) show this point to be very constant and sharply marked. On comparing the discharge curves for clean and dirty wires (see Fig. 7), however, it

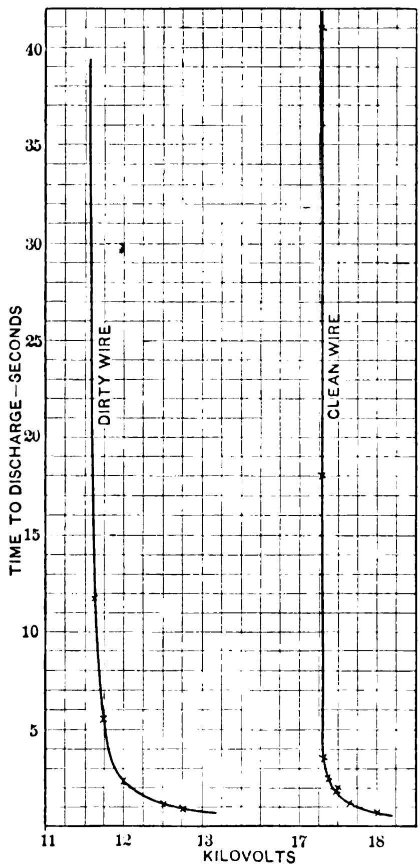

FIG. 7.—Discharge curves—clean and dirty wires 0.276-cm. wires in 6.35-cm. tube

will be seen that the break in the curve is less sharply marked for the dirty wire and the bend more gradual. This indicates a lesser supply of ions, but a supply amply sufficient to cause a rapid discharge of the sensitive electroscope. It is thus apparent that the figure 37,850 has no significance, only representing the value at which the first surface irregularities begin to dis-

charge. These discharges represent energy loss, and in sufficient quantity may cause the voltage at which appreciable loss begins, to fall far below the value for clean wires.

Influence of Moisture

The method of securing any degree of moisture content of the air has been described. The continuous draft of air through the apparatus, with temperature and moisture instruments close to entrance and exits, ensures a constancy of conditions not possible with the closed cylinders used by Ryan and Watson. Moist air was also obtained by drawing it upward through a dense spray, and by taking it from outside the building on rainy days. The invariable conclusion from many experiments is that moisture in the air has no influence on the surface intensity at which ionization and loss begin. Several sets of observations are given in Table V. The observed and corrected primary voltages are given and also the conditions of temperature, pressure, and moisture content. A range of relative humidity from 0.1 to 0.9 was covered. The " vapor product " as defined by Mershon is also given in the last column, and ranges from 0.008 to 0.83; this quantity is the product of the relative humidity by the vapor pressure in inches of mercury.

Mershon, working on aerial wires, concludes that moisture lowers the critical voltage by about 16 per cent for a range of vapor product 0 to 0.6. Since his wires were exposed to weather they were subject to some degree of surface imperfection. Since such imperfections are an aid to condensation of moisture it was thought that a lowering influence of moisture might be possible in this way. A series of tests with moist air was therefore made on the dirty wire already described. The results as given in Table VI indicate that in the case of dirty wire also, the moisture content of the air has no influence on the value of voltage at which ionization and loss begin. A possible influence of the velocity of the air through the apparatus in checking condensation was also investigated by drawing moist air through for some time, testing for critical voltage, then stopping the air draft and testing, etc. In no case was it possible to detect any influence of the moisture content on the critical voltage.

It is difficult to imagine any other conditions of Mershon's experiments which might explain an influence of moisture. His wires were suspended by paraffined cords over which the loss was only one or two per cent, and consequently all losses save those

in the atmosphere itself were practically eliminated. Floating particles and mist depositing on the lines would lower the critical voltage but with given surface conditions, the experiments de-

TABLE V. CRITICAL VOLTAGE—MOISTURE CONTENT—CLEAN WIRES

Primary volts at which discharge begins	Temperature of entering air deg. cent	Temperature of dew point deg. cent	Barometer mm.	Primary volts corrected 21 deg. and 760 mm.	Relative humidity	Vapor product
0.206 cm. diameter						
60.3-5, 60.3	20	-4	764.5	59.96	0.194	0.025
60.5	19	5	764	59.93	0.4	0.102
60.2, 60.1	21	8	764.5	59.9	0.433	0.136
60, 60.1	23	16.5	764	60.07	0.65	0.38
59.9, 60	24.8	18	764	60.21	0.68	0.41
59.2	27	23	763.5	59.71	0.82	0.624
59	28	25	763.5	59.62	0.9	0.833
60.5	20	0	763.5	60.07	0.264	0.047
0.276 cm. diameter						
68.8	21	-10	761.5	68.7	0.108	0.008
68.8, 68.9	21	-2.5	761.5	68.75	0.208	0.031
68.8, 69	20.4	1.5	761.8	68.8	0.293	0.060
68.8	24	8.5	762.8	69.2	0.374	0.122
68.8	25	13	762.8	69.2	0.47	0.204
68.5, 68.8	26	16	763	69.1	0.546	0.292
69	21.6	15	763	68.9	0.66	0.33
68–69	23.4	18	763	68.7	0.72	0.43
68.5–69	20	17	760	68.7	0.86	0.504
0.347 cm. diameter						
75.3	19.6	3	760	75.0	0.33	0.072
75.2	19.8	8	760	75.0	0.46	0.147
75.1–75.5	22	12.5	760	75.4	0.54	0.23

scribed above indicate an entire absence of any influence of moisture. Mershon also finds that the rate of loss beyond the critical voltage increases with the vapor product. Here also no obvious explanation offers itself. The curves of the present

experiments between discharge rate of electroscope and voltage show that either the number or the velocity of the free ions about the wire is lessened in moist air, and this means a less loss. This result is in conformity with those of many other experiments. It has long been known for instance that the conductivity of air is lessened by moisture; also that the velocity of ions is less in moist air than in dry air. Steinmetz notes an increase of electric strength of air by the presence of fog and steam. Zeleny has shown that between dryness and saturation the voltage of initial discharge between a point and a plane is constant for negative potentials, and varies by less than 1.5 per cent for positive potentials. He also shows that the currents of discharge are both lowered with increasing moisture content.

TABLE VI. CRITICAL VOLTAGE—MOISTURE CONTENT—DIRTY WIRE 0.297 CM. DIAMETER

Primary volts at which discharge begins	Temperature of entering air deg. cent	Temperature of dew point deg. cent	Primary volts corrected 21 deg. and 760 mm.	Relative humidity	Vapor product
46.5 47	19	0.5	46.2 46.7	0.282	0.05
46.5 47	19	6	46.2 46.7	0.428	0.11
46 46.2	20	9	45.8 46	0.49	0.16
46 46.5	21	12.5	45.9 46.4	0.58	0.24
45.5 46	25	18	45.8 46.3	0.65	0.39
45.5	26	19	45.9	0.65	0.41

When the critical voltages observed by Mershon are reduced to electric intensities at the surface of the wires they are found to be well below these of Ryan, Watson, and the values given in this paper. For example, the loss from a 0.472-cm. wire, according to Mershon, begins at a surface intensity 35,000 volts per cm., see Fig. 6; the value found in the present experiments for the same size wire is 51,000. This difference of 30 per cent can only be accounted for in three ways: (1) The method of taking the critical point from the loss curves. (2) Dirt and irregularities on the wires. (3) Break-down of the air near the strings at a lower value than that necessary on a free wire. Examination of the curves show that the critical point is taken close to the sharp

upward break of the curves, and the method offer small chances of too low a choice of critical value. Dirt and irregularities will lower the critical voltage, but require extreme conditions for as great a lowering as 40 per cent, as is indicated by the experiments already described. With the larger wires used by Mershon, it does not seem possible that this degree of surface irregularity could result from any deposit from the air. The third possibility mentioned seems to have been eliminated by the tests to which the cords were subjected before using.

In view of these discrepancies, one naturally turns to Mershon's method of measuring the loss as a possible source of error. This method involves the elimination, by means of a differential wattmeter, of transformer losses aggregating several times the value of the loss to be measured. The method is elegant in conception, but in view of the small losses to be measured, it is to be regretted that its accuracy could not be tested further than described. Since Mershon's observations appear to have been taken in all seasons, it may be stated that a range of temperature of 35 deg. cent. and of pressure of 25 mm. of mercury, and an error of 5 per cent in the critical point as taken from the curves, would give a range of critical voltage as wide as that attributed by him to moisture.

Experiments on Coronae

One of the most striking phenomena in the experiments already described is the extreme sharpness with which the critical voltage appears. The sharp stoppage of the electroscope discharge on interrupting the alternating voltage, and the coincidence of discharge curves for ascending and descending voltage, in the present investigation, indicate that any after-effect of the ionization due to corona must be of duration less than one-half a period. Ryan showed in beautiful manner how the appearance of corona was accompanied by a hump on the charging current curve in the neighborhood of the maximum of the voltage wave, thus suggesting a periodic character. In order to investigate these phenomena further the following stroboscopic device was used. A 0.156-cm. polished copper wire was stretched along the axis of an outer cylinder of 10.5 cm. internal diameter, and voltage applied between them. The wire was viewed longitudinally through six slits, each 4.7 mm. wide, in a disk driven by a six-pole synchronous motor; the slits were on a circle of 27 cm. radius. The position of the eye was fixed by an eye-

piece on a screen movable about the motor axis; this screen had a small radial slit 0.5 cm. wide, under the eye piece and opposite the circle of slits in the revolving disk. The angular position of this slit was read on a circular scale. The eyepiece therefore moves through 56 cm. in covering the interval corresponding to one period of the alternating circuit. On viewing the corona with this apparatus, it is at once found that there are certain regions where it cannot be seen and others where it is readily visible, thus showing its periodic character. Further the points of separation of dark and bright regions are sharply marked, so that it is possible to determine quite accurately over how great a proportion of a period the corona exists. A set of observations

TABLE VII. LOCATION OF CORONA ON VOLTAGE WAVE

Primary volts	Corona appears			Corona disappears			
	Degrees of scale	Electrical degrees		Degrees of scale	Electrical degrees		Starting Intensity
		Reading	Corrected		Reading	Corrected	
105	10.4 10.8	31.8	27.1	50 50	150	143.5	66,500
100	12.5 12.7	37.8	33.1	48 47.2	142.8	136.3	68.300
90	14.6 15.4	45	40.2	45.4 45.4	136.2	129.7	74,200
80	16.6 17.4	51	46.3	43.8 44.2	132	125.5	70,000
70	19 19.2	57.3	52.6	42 42	126	119.5	70,500
65	27.6 27.8	83.1	78.4	34.6 34.2	103.2	96.7	70,600
65	26.5 27	80.2	75.5	33 33.2	99.3	92.8	—

for various voltages, above the critical value, are given in Table VII. The first column gives the voltage on the transformer primary; the second column, the scale reading at which the corona becomes visible advancing the eye piece from the dark region towards the bright, and in a direction contrary to that of the motion of the disk. The observation therefore is of the angular position at which the corona ends. The readings of two independent settings of the eyepiece are given for each voltage to indicate the accuracy. The position corresponding to zero value of electromotive force was obtained by an instantaneous contact device and voltmeter connected across the transformer primary. The third column gives the average readings reduced to electrical

degrees, and the fourth column these values corrected for the width of the slit and referred to the zero value of electromotive force determined as described above. The succeeding columns give the corresponding readings of angular position at which the corona can no longer be seen. This observation is therefore the angular position at which corona begins on the rising side of the electromotive force wave.

The results in Table VII indicate that the corona corresponding to a given voltage will persist on the decreasing side of the wave to a value below that at which it starts on the side of rising voltage. After the intensity drops below the value at which ionization begins the foregoing plentiful ionization is able to preserve luminosity for an appreciable interval. This interval is seen to be extremely short and of the order of magnitude of one or two thousandths of a second. In fact the settings for vanishing point of corona on the side of decreasing voltage are somewhat less sharply marked indicating that the corona fades off more gradually than it starts. The readings for 65 volts primary taken on different days show some discrepancy. The corona is very faint at this voltage close to the peak of the electromotive force wave and therefore very sensitive to reading error and voltage variation. In this region, also, the accuracy of setting is somewhat impaired by the presence of the three peaks of the electromotive force wave.

The wave form as measured from the oscillogram is plotted in Fig. 5, and the ordinates at which the corona starts and ceases for the several values of primary voltage are indicated; the voltage is rising on the left side of the curve. The ordinates corresponding to the angles given in Table VII indicate voltage values which by obvious calculation permit the evaluation of the figures for surface intensity at which the coronæ begin. These values are given in the last column of Table VII. They are in fairly good agreement, considering the method by which they are obtained with the accurate figure for this wire 65,800 as determined with the electroscope. It is altogether probable that this latter figure is the real value at which the corona starts on the rising side of the wave, and if it be taken as a basis the lag of the point at which corona vanishes would be somewhat lessened from the values indicated in Fig. 5.

Positive and Negative Coronæ. The arrangement of apparatus as described above superimposes the coronæ corresponding to the positive and negative halves of the electromotive force cycle.

By closing alternate slits in the revolving disk it is possible to view the positive and negative coronæ independently. Several sets of readings were made for each half wave of the angle at which corona begins and ends. The readings for the two half waves were made on the same portion of the scale by reversing the field of the synchronous motor. The points of beginning and ending of corona were found to be independent of the polarity of the wire. There was very little difference to be detected in the appearance of the two coronæ; if there is any difference it is a somewhat greater brightness and sharper definition of one.

The extreme sharpness with which the corona appears was well illustrated in the stroboscopic experiment in various ways. For example, when viewing the corona near the position at which it is cut out, very small voltage fluctuations are reflected as flickers in the corona. By setting the eyepiece very near to the position of eclipse, a regular pulsation of the corona was generally visible, and was traced to a slight hunting of the motor, thus causing a vibration of the eclipsing edge of the hole in the disk about its true synchronous position. A further evidence of sensibility could be seen by adjusting the voltage so that the critical value was in the region of the three peaks on the crest of the wave, as shown in Fig. 5. It was then possible by moving the eyepiece to pick out the several peaks separated by the dark intervals corresponding to the depressions.

Diameter of Corona. It has been suggested by Steinmetz and others that the diameter of the corona is such as to reduce the electric intensity at its boundary to the constant value of the electric strength of air, *i.e.*, about 40 kilovolts per cm. Jona states that the diameter of the corona for a given arrangement of conductors is independent of the size of the wire and depends only on the voltage. Also that the diameter is such as to reduce the electric gradient at its boundary below the electric strength of air. The same suggestion has been made by Russell in several places.

The measurement of the diameter of the corona is very difficult. Jona's figures and conclusions are apparently based solely on eye estimates of the diameter. Photographic methods fail, since the phenomenon is accompanied by much invisible ultraviolet radiation. A preliminary attempt looking to the development of a method for measuring the diameter of the visible corona is described below; it has yielded results which are suffi-

ciently concordant to make them worthy of recording here. The experiments are being carried further in this most interesting direction.

A slit was cut in the wall of the outer 15.2-cm. cylinder and at right angles to the axis. A 0.156-cm. wire stretched along the axis develops a well defined corona for voltages above 18,000. A screen one cm. wide was placed transversely across the slit and close to the wall of the outer cylinder. The screen was moved up and down to positions in which its upper and lower edges cut off the corresponding edges of the corona, the eye being at a pin hole at the horizontal level of the wire and at a distance from the wire 6.15 times that of the screen from the wire. It is necessary in these experiments that the eye be thoroughly rested and accustomed to the darkness. In making the final setting

TABLE VIII. DIAMETER OF CORONA, 0.156-CM WIRE IN 15.2-cm CYLINDER

28,000 volts				24,000 volts			
Top	Bottom	Difference	Diameter corrected	Top	Bottom	Difference	Diameter corrected
11.065	10.45	0.615	0.462	10.335	11.065	0.73	0.324
11.03	10.43	0.60	0.48	10.375	11.035	0.66	0.408
11.02	10.41	0.61	0.468	10.335	11.06	0.725	0.33
11	10.41	0.59	0.492	10.355	11.06	0.705	0.354
11	10.41	0.59	0.492	10.375	11.06	0.685	0.379
11.035	10.375	0.66	0.408				
Average diameter.......			0.468	Average diameter.....			0.36

of the point at which the screen completely obscures the corona edge, direct scrutiny is not possible owing to the blind property of the fovea of the eye, and use must be made of the adjacent regions of the retina. In this way any number of quite consistent readings may be taken. The screen was carried on a cathetometer which could be read to a hundredth of a millimeter. The results at effective voltages 28,000 and 24,000 are given in Table VIII. They show that the maximum deviations from the average values of observed diameter are of the order 10 per cent to 15 per cent. This must be regarded as fair, in view of the small diameters measured, and offers good promise for further investigation in this direction.

As corrected for the width of the screen and the angle at the eye, the diameters of the coronæ at 28,000 and 24,000 volts are

0.46 cm. and 0.36 cm. respectively. The values of electric intensity at the edge of the coronæ, calculated on the assumption that the conductor is enlarged to these diameters, *i.e.*, that the corona has no resistance, are 50,250 and 51,700 volts per cm. respectively. The values of intensity at which the corona forms on solid wires of diameters 0.46 and 0.36 cm. are 51,500 and 54,000.

While it is hazardous to draw conclusions from work as yet so incomplete the above figures for a solid wire and a corona assumed to be perfectly conducting are in such close agreement as to at least suggest: First, that the edge of the corona marks the limit of ionization or rupture; and second, that the corona has high conductivity, the greater part of the potential difference, and hence loss, occurring beyond its boundary. On this assumption the loss would be due to the forced passage under the electric gradient of molecular ions through the air. It is to be noted however that these figures do not indicate that the intensity at the edge of the corona is 40,000 volts per cm., the suggested constant electric strength of air, but that it is higher and its value related to the corona diameter in the same way that the critical surface intensity for a solid wire is related to the diameter of the wire.

Discussion and Conclusions

It is evident from the facts and experiments which have been described above that the laws under which the corona appears are not yet definitely fixed. There are a good many consistent facts, however, which permit us to speculate as to the nature of the corona. The most conspicuous of these facts is that the break-down of the air which is invariably accompanied by a more or less visible corona is attended by copious ionization. Our present knowledge of ionization of gases reveals three possible sources of ions or charged particles: (*a*) the ions may be drawn from the substance of the wire or terminal itself under the electric intensity; (*b*) the molecule of the gas may be disrupted by a separation of its two component charges by the intensity of electric field in which it finds itself; (*c*) a molecule of a gas may be ionized or separated into its component charges as a result of a collision between itself and another molecule or charged particle.

Regarding the possibility of drawing free charges from the metal of the terminals, we have the experimental evidence that the generation of ions in the neighborhood of wires is independent

of the material of the wires and we should expect different figures for different materials if initial ionization started in this way. Further it has been calculated that the electric intensity necessary to draw electrons from metal is of a very much higher value than that at which corona begins. With reference to the second possible source (*b*), it has also been shown that the intensity necessary to separate the component charges of a molecule is higher considerably than the intensity at which corona begins at atmospheric pressure.

There is considerable evidence that the third source of ionization mentioned above, *i.e.*, ionization by collision, or secondary ionization as it is called, is that which leads to the starting of corona. There are always a certain number of free electrons or negative charges and of ions of molecular size present in the air at atmospheric pressure. These free charges have their origin in the frequent collisions between molecules and are extremely few in number. A single charge does not have a long independent existence but when it combines with a molecule of opposite charge its place is taken by other charges, so that the average condition is that of a constant number of free charged particles. These charged particles account for the conductivity of the air which may be observed by sensitive instruments. It is the value of this low conductivity which leads to our knowledge as to the number of free charges present.

Now the electron, or corpuscle, the smallest negative charge of which we have knowledge, requires an intensity in the neighborhood of 170,000 volts per cm. in order to give it a velocity sufficiently great to break up a molecule with which it collides. The corpuscle attached to a molecule, however, has a larger mass and consequently if it can acquire sufficient velocity it can the more readily break up a molecule with which it collides. These are the agents which are active in secondary ionization, which has been investigated by many physicists, notably J. J. Thomson, Townsend and von Schweidler. The values at which this class of ionization sets in as determined by physicists working with continuous potentials and generally in vacuum tubes, is between thirty and forty thousand volts per cm. This figure is in very good accord with the value at which corona sets in for wires above one cm. in diameter. The influence of temperature and pressure is also the same in each class of phenomena. It may be stated then with some positiveness that secondary ionization is the cause of the initial break-down of the air and formation of corona.

It is evident that in the formation of the corona very short time intervals are involved, for it begins in the close neighborhood of the maximum value of the intensity wave, and, within the comparatively narrow limits already investigated, is independent of the frequency. It begins and ends at approximately the same value on the wave of intensity when the maximum intensity is above the critical value. If we try to picture the phenomenon of the starting of break down we may reason somewhat as follows: In an alternating electric field the free ions of molecular size vibrate with increasing amplitude as the voltage arises. The velocity is greatest at the maximum value of voltage if as is probable we presuppose some retarding force. If, however, the ion meets nothing its amplitude will be greatest at the end of a half wave. We may suppose that there are always some ions which collide with molecules when their velocity is a maximum. When with increasing voltage this maximum velocity is sufficient to ionize the molecule with which the ion collides secondary ionization sets in liberating more free ions which themselves become ionizing agents and a cumulative effect sets in at once resulting in a general state of ionization.

The intensity (40,000 volts per cm.) at which secondary ionization sets in around large wires corresponds with the value deduced by Russell for the discharge intensity between terminals of various shapes about which there can be no preceding ionization. In cases where there is antecedent ionization the effective terminal enlarges until the intensity at its surface falls to the ionizing value as is indicated by the experiments on the diameter of the corona described above. The value 38 to 40 kilovolts per cm. satisfies many of the cases of discharge which arise and thus offers itself as the long sought constant value of electric strength of air.

There is one important case, however, which is not yet harmonized with this value, namely the case in which the radius of curvature of the terminal is small, the most conspicuous instance being the range of diameter of round wires of less than one cm. In these cases the apparent intensity at which ionization begins is much higher than 40,000 volts per cm. The value of intensity may be carried to 80,000 for small wires and there is not the slightest trace of ionization. To state that the air has a different strength near the wire than at a distance is only another way of stating the fact and dodges the question. As the diameter is decreased it becomes comparable with the space

separation of the free ions. There is considerable evidence that under normal conditions there are about 1000 of these ions per cubic cm. of air. This would give them an average distance of separation of about 1 mm. Thus as the ions vibrate near the wire surface they must be brought much nearer together in the case of a small wire. Hence there will be larger forces of repulsion brought into play retarding or limiting the amplitude of vibration and thus necessitating higher values of intensity to overcome these forces.

These are questions for solution by the experimental physicist but the field is at present practically untouched. The application of alternating electromotive forces to the problems of the ionization of gases has been absolutely neglected. Corona formation and the laws which regulate it are of the first importance for electrical engineers since corona is to be prevented both as a source of loss and an enemy of insulation. The field is replete with fascinating problems. Their solution however involves the use of methods and apparatus generally not familiar to the physicist. Hence it is to be hoped that this most interesting field will be entered more generally by experimental engineers.

The experiments described in this paper were carried out at the Johns Hopkins University. The author wishes to acknowledge the valuable assistance of Dr. C. F. Lorenz and Mr. P. G. Agnew.

Summary of Results

The conclusions from the experiments of this paper may be briefly summarized as follows:

1. A method is described which permits the determination of the electric strength of air near round wires within 0.5 per cent.

2. Values of the electric strength of air near clean smooth wires of diameters between 0.08 cm. and 0.5 cm. have been determined.

3. Temperature and pressure cause the greatest variations in the electric strength of air near a given wire.

4. At 760 mm. pressure there is a drop or rise of 0.22 per cent in the electric strength of air per centigrade degree rise or fall from 21 deg. cent.

5. Water vapor or moisture has no influence on the electric strength of air. Increasing moisture content probably lessens the loss above the critical voltage.

6. There is no loss through air until the critical voltage accompanied by ionization and corona is reached.

7. The electric strength of air is independent of the material of the wire or terminal.

8. The critical voltage may be markedly lowered by dirt and surface impurities. This lowering may be as great as 33 per cent.

9. The corona is periodic but ceases at a somewhat lower value on the voltage wave than that at which it begins.

10. The corona has high conductivity and most of the loss takes place beyond it.

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NOTE

The following paper is to be read at the 27th annual convention of the American Institute of Electrical Engineers at **Jefferson, N. H., June 28–July 1, 1910.** This paper is to be presented under the auspices of the High Tension Transmission Committee of the Institute. All those connected with the Institute and desiring to take part in the discussion of this paper may do so by being present at the meeting; or, if this is not possible, by sending in a written contribution.

Written contributions will be read at the meeting, time permitting, for which they are intended, either in full, in abstract, or as a part of a general statement giving a summary of the views of those taking the same position in the matter.

The principal object in getting out the paper in advance of the meeting is to enable and encourage those not in a position to attend the meetings to take part in the discussion by mail.

Contributions to the discussion of this paper should be mailed to **Ralph D. Mershon, Chairman High Tension Transmission Committee, 60 Wall Street, New York,** so that they will be received not later than June 23, 1910.

A paper to be presented at the 27th Annual Convention of the American Institute of Electrical Engineers, Jefferson, N. H., June 28–July 1, 1910.

DETERMINATION OF TRANSFORMER REGULATION UNDER LOAD CONDITIONS AND SOME RESULTING INVESTIGATIONS

BY ADOLPH SHANE

INTRODUCTORY

For some time past the writer has been suspicious of the accuracy of the results obtained in calculating transformer regulation by the now popular method of adding the impedance volts vectorially to the pressure impressed on the load, the data for the impedance triangle being obtained by the common short-circuited secondary method and by the measurement of the resistance of the transformer winding. Indeed, the only check on this method heretofore has been the comparison with the direct method of reading the primary and secondary pressures, reduced to like terms, and ascertaining the difference, or, what amounts to the same thing, reading the secondary pressure under full (current) load and under no load, keeping the primary pressure constant the while. These direct methods are inexact unless great precautions are taken due to the impracticability of reading normal pressures with sufficient degree of accuracy for this purpose.

For example: Suppose the normal e.m.f.s of a transformer can be read to an accuracy of 0.25 per cent and the regulation is actually 2.5 per cent. The value of regulation may be found to be anywhere between 2.25 per cent and 2.75 per cent, causing a possible maximum error of 0.5 per cent in 2.5 or 20 per cent in the value of the regulation.

If some means could be devised whereby the regulation volts might be read off directly by a low-reading voltmeter, results of the same order of accuracy as the reading of normal pressures

could be obtained. It is the purpose of this paper to point out such a direct method, as well as an accurate calculated method, to check the results obtained with particular transformers, to point out errors existing in the ordinary calculated method referred to above, and, as far as possible, to give the causes for such errors.

Transformer Regulation

1. *The Direct Method.* If two transformers, A and B (Fig. 1) exactly alike, be connected to the same source of power their secondaries connected in opposition series, the e.m.f. between the open ends a b will be zero until load is applied to one (A) of the secondaries, when this e.m.f. is equal to the *true* impedance pressure of the loaded transformer.

If now a third transformer C is connected to the line and its

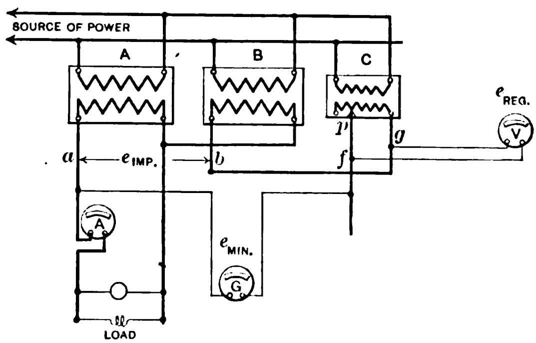


FIG. 1

secondary connected in series with the other secondaries, but in opposition to B, and a galvanometer G connected to the free terminals of this secondary series system we have the electrical connections necessary for the proper performance of the test.

Normal load is applied to transformer A. The secondary winding of C is gradually cut out of the circuit, turn by turn, by shifting the contact point P along the winding, until the galvanometer G reads a minimum. The e.m.f. of the secondary C between the points f, g is the regulation volts required for transformer A and may be read off directly by a low-reading voltmeter V.

Theory. Fig. 2 represents the common transformer vector diagram using 1 to 1 ratio of transformation for simplicity, with the secondary current I'' lagging θ deg. behind the secondary

terminal pressure e''. If to this pressure is added vectorially the secondary resistance and reactance drops ($R''\,I''$ and $X''\,I''$ respectively, Fig. 2) the secondary induced e.m.f. E'' is the result. This is also the e.m.f. of self-induction of the primary. That part of the impressed e.m.f. which overcomes this latter is designated in the figure by e', equal and opposite in vector position to E''. To this is added vectorially the primary resistance and reactance drops, producing finally the impressed e.m.f., E'.

The foregoing represents the load conditions of transformer *A* in Fig. 1. Transformer *B* being unloaded has a secondary e.m.f. equal and opposite to the primary. Thus in Fig. 2, E' also represents the primary e.m.f. of *B*. Equal and opposite to this is the secondary e.m.f., *E*, which leads the terminal pressure e'' of transformer *A* by a small angle α. The vector difference $c\,a$ of these two e.m.fs. (e'' and *E*), which are respectively the secondary pressures under load and no load, represents the total impedance drop $Z\,i$ or e_{imp} of the transformer (*A*) under load. The vectors $a\,b$ and $b\,c$ are respectively the resistance and reactance drops $R\,I$ and $X\,I$ of the transformer, each being made up as follows:

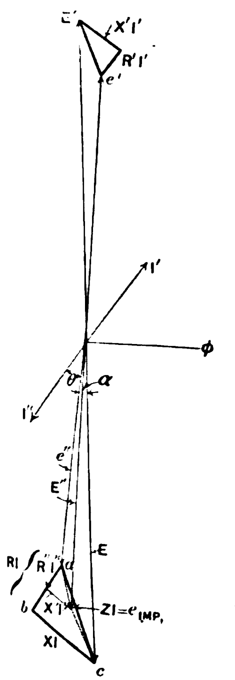


Fig. 2

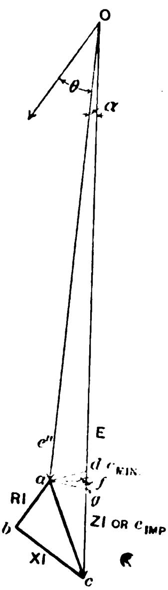


Fig. 3

$$R\,I = R'\,I' + R''\,I''$$

$$X\,I = X'\,I' + X''\,I''$$

The *working* transformer diagram is represented by the two vectors e'' and *E*, capped by the impedance triangle $a\,b\,c$. This is shown separately in Fig. 3 for clearness. The lengths of the vectors e'' and *E* are, however, made longer, without any

corresponding increase of the impedance triangle, in order to more nearly represent actual relative conditions.

Consider now the third transformer C. Since it is unloaded and since its secondary is connected in opposing series with B the secondary pressure is exactly 180 deg. opposite to E, the terminal pressure of B, but variable in value, depending on how many secondary turns are in the circuit.

This is shown in Fig. 3, $c\,g$, $c\,f$, or $c\,d$ representing the variable secondary pressure of transformer C, opposing $O\,C$ or E. The only e.m.f. active between the secondary terminals of A and B is the impedance pressure e_{imp}, since these two secondaries are in opposing series. The points $a\,b$ between which this pressure exists is indicated in Fig. 1, and the vector position is $a\,c$ in Fig. 3. The pressure at the terminals of the entire secondary system is $a\,g$, $a\,f$, or $a\,d$, since the e.m.f. of C partially opposes e_{imp}. The instrument G of Fig. 1 indicates the value of this final resultant pressure, which may be any value depending on the number of active turns in the secondary of C. But there is a *definite* minimum value caused by the correct number of active turns in C. Any increase or decrease of this particular number will *always* cause an increased reading of G. This is clearly shown in Fig. 3. With $c\,d$ as the pressure of C, there is a corresponding value $a\,d$ for the secondary pressure of the entire system. Similarly for $c\,g$ there is a corresponding pressure $a\,g$ and for $c\,f$ there is $a\,f$. Manifestly $c\,f$ is the particular pressure of C which causes $a\,f$ $(= e_{min})$ to be the minimum, $a\,d$ and $a\,g$ being each greater in value. From the geometry of the figure e_{min} must be perpendicular to E for this condition. Since in any modern constant pressure transformer the angle a is very small, $O\,f$ differs from $O\,a$ or E'' in but a very minute degree. Hence the difference between E and e'' is very closely $c\,f$. But this difference is the regulation volts sought after. Therefore the regulation volts e_{reg} may be read off directly by a low-reading voltmeter of suitable scale connected to the active secondary terminals of C, after the adjustment for e_{min} has been made.

II. *The Calculated Method.* If the common short-circuited test should give data for the correct impedance triangle, the value of regulation obtained by this means would be above criticism. But such is not the case as will be shown later. The true transformer impedance volts can be found only under actual load conditions. This is e_{imp} referred to above. Hence to find the true impedance triangle the transformer C is dispensed with,

the connections of A and B remaining precisely the same. A wattmeter suitable for the full-load current of transformer A and for low voltage, is inserted into the load circuit (W_2 in Fig. 4) the pressure terminals being connected to the free secondary ends a b, precisely where the low-reading voltmeter V_2 is connected to indicate e_{imp}. The reading of this wattmeter is the true $R I^2$ loss of A under load conditions. With the above two readings and the load current the correct impedance triangle may be found. That is, dividing the value of the wattmeter reading by the value of the load current gives the $R I$ drop, which together with the impedance drop solves the triangle. From thence on the calculations are as usual in such cases.

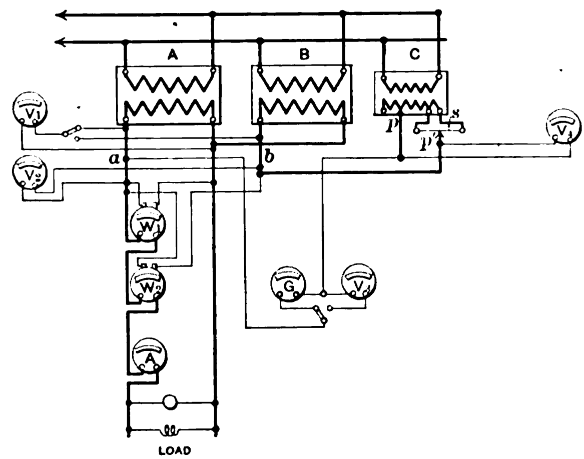


FIG. 4

It may be argued that it might not always prove easy to procure two absolutely identical transformers for the above methods, that the voltage ratios might be just sufficiently different to spoil the test. In answer to this it might be said that the writer had at his disposal three pairs of transformers, each pair of different manufacture, and these checked out very well. The check was made by connecting a delicate alternating current galvanometer to the free ends of the secondaries of each pair connected in opposed series. Scarcely a deflection in any case was observed, though the trifling load of a wattmeter pressure coil connected to the secondaries of one transformer caused sufficient unbalancing to give a decided deflection. This would indicate that absolute voltage equality should be the rule rather

than the exception with similar transformers from the same manufacturer. A fairly elaborate test was made to substantiate the above theory, the results of which are incorporated in curves of Figs. 5 and 6. These curves all refer to the regulation volts with respect to power factor, of a particular pair of transformers with noticeably small leakage. Fig. 5 is the curve obtained by the direct method (I) using three transformers. Attention is called to the generous scale of volts in spite of which the observed points appear very consistently on the curve. Curve A, Fig. 6, is a duplicate of Fig. 5, without any points being present belonging to this particular curve. The points (.) so near this curve as to seem to form part of it were really obtained by calculation, using method II of this paper. One checks the other. The points (x) represent the values obtained by carefully taking the

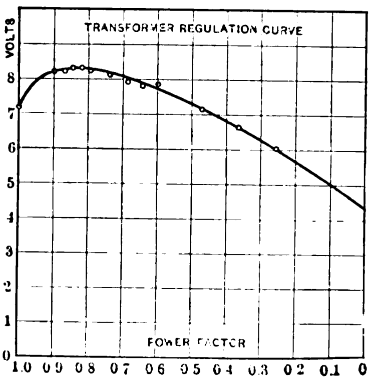


Fig. 5

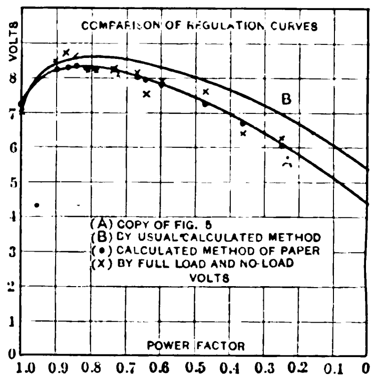


Fig. 6

difference between the no-load and load values of e.m.f. ($E - e''$). Of course the inherent inaccuracy of this method is evident by the staggered position of the points, but they agree closely enough with curve A to confirm the above methods. Curve B is the regulation curve obtained by the usual short-circuit test and resistance measurement, and the departure from the three lower sets of results is marked. So decided is the discrepancy that the writer believes, by the use of an ordinary voltmeter, taking full load and no-load readings, the truth is more nearly told. True, the regulation curve is not relatively so consistent and smooth in this latter case, but any point by reasonable care may represent less percentage error than a corresponding point on the calculated curve by the short-circuit test.

The Test. More than one set of transformers were tested for regulation, but only a sample of one set of readings are here given. The data for both methods were taken at the same time, the connections for the test being as indicated in Fig. 4. Transformers A and B were exactly alike, rated at 2 kw. each, with 220 volts secondary. It was found that with 12.5 amperes load (12.56 corrected) no excessive heating ensued, so the current was maintanied at this value. Transformer C also happened to be rated at 2 kw. though the value of capacity here is immaterial. The regular secondary winding was not used. Instead, a few turns of wire were wrapped over the fixed windings, care being taken to have a somewhat greater total e.m.f. here than the impedance of transformer A, since at one point of the regulation curve, the impedance pressure equals the regulation.

Each turn was brought out to a switching arrangement whereby it could be instantly cut in or out of circuit, excepting the last turn, the terminals of which were connected to a slide-wire resistance allowing perhaps one ampere to flow. The purpose of this latter arrangement was to permit of exact adjustment for e_{min}. The procedure followed was to start with the full number of turns active, gradually cutting them out one by one until the galvanometer G indicated as near a minimum value as possible, the final adjustment being made by moving the point P' along the slide-wire S.

The accuracy of the method depends on C not being perceptibly loaded, and it might be supposed that the current through the slide-wire S does load the transformer to some extent. That the amount is imperceptible may be shown by a numerical example which closely fits this case. Assuming one volt per turn, 220 volts normal e.m.f., and 10 amperes normal load, we find that this load represents 2200 ampere-turns. The one ampere flowing through the slide-wire connected to the terminals of one turn represents but one ampere-turn. The transformer is thus loaded to less than 0.05 of one per cent, an entirely negligible value.

Voltmeter V_1 was so connected that by means of a switch it could quickly indicate the load and no-load pressures across the terminals of A and B respectively. V_2 indicated the impedance drop under load conditions, V_3 the minimum volts after adjustment had been made by the use of G and V_4 the regulation volts. Actually V_2, V_3, and V_4 were represented by one instrument, a low reading voltmeter, which by suitable switches could be

readily thrown to the several points. But one instrument was used to insure correct relative readings for purposes of accurate checks. Wattmeter W_1 was connected to read the load. W_2 having its pressure coil connected to the impedance voltage terminals ($a\ b$ in Fig. 4) indicated the copper $I^2 R$ under load conditions. It had ample current capacity and the pressure coil was adjusted for low voltage. The instrument was found to be accurate for low power-factors. The ammeter A indicated the current load which was maintained at 12.56 amperes. The galvanometer G was merely a piece of annealed iron suspended in a coil and damped with oil. This proved amply sensitive All the instruments were thoroughly dead beat which vastly facilitated the taking of readings and thus guarded against a change of conditions during the taking of a set of observations.

The load consisted of a lamp bank in parallel with a variable ironless inductance. By this means a power-factor as low as 25 per cent was obtained. Constant temperature conditions were reached before any readings were taken.

TABLE I.

	a	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*i*	*j*	*k*	*l*	*m*	*n*	*o*
No.	Amp. load	Watts $I^2 R$	Watts load	Volts load	Volts no load	Volts min.	Volts imp.	Volts reg.	Room temperature C°	Resistance primary by bridge	Resistance secondary by bridge	Power factor $\frac{c}{a \times d}$	Volts reg. $e - d$	Volts reg. calculated	$\sqrt{f^2+h^2}$
1	12.56	89.5	2650	207.7	214.7	4.27	8.29	7.11	24.4	0.252	0.278	1.00	7.0	7.124	8.29
2	"	"	2310	204.0	212.4	0.9	8.24	8.2	24.0			0.901	8.4	8.26	8.25
3	"	"	2240	204.7	213.4	0.8	8.235	8.23		0.252	0.278	0.87	8.7	8.293	8.23
4	"	"	2146	200.0	208.6	0.8	8.30	8.25	24.0			0.855	8.6	8.295	8.29
5	"	"	2095	203.4	211.6	1.02	8.31	8.3				0.82	8.2	8.275	8.36
6	"	"	2023	202.2	210.4	1.34	8.30	8.2		0.251	0.279	0.796	8.2	8.245	8.3
7	"	"	1864	200.8	209.0	1.85	8.33	8.13	25.0			0.738	8.2	8.117	8.33
8	"	"	1728	201.3	209.4	2.45	8.30	7.95				0.684	8.1	7.97	8.32
9	"	"	1618	199.6	207.1	2.8	8.30	7.87	24.0	0.252	0.278	0.645	7.5	7.85	8.35
10	"	"	1497	198.6	206.4	3.21	8.30	7.8				0.60	7.8	7.68	8.45
11	"	"	1168	198.0	205.6	4.232	8.28	7.14	24.0			0.47	7.6	7.14	8.3
12	"	"	925	201.0	207.4	4.97	8.29	6.65				0.366	6.4	6.63	8.3
13	"	"	637	202.0	208.2	5.56	8.26	6.01	24.0	0.252	0.277	0.251	6.2	5.97	8.2

The original data are given in Table I. The sets of readings from 1 to 13 inclusive were taken at nearly normal impressed

voltage with power-factors ranging from unity to 25 per cent. This table furnished the data for the curves of Figs. 5 and 6. In Table II the load power-factor was maintained unity, but the e.m.f. was varied from normal to practically zero value. Care was taken to keep the current exactly constant throughout the test.

Inspecting Table I down through the thirteen sets of readings it is seen that with a steady current and voltage about normal (columns a and d), the copper loss (column b), read by W_2 remained constant, though the power factor (column 1) varied from unity to 25 per cent, that is, the real power dropped from 2,650 watts to 637 watts (column C). It is also seen that the impedance volts (column g) remained sensibly constant during like conditions. The difference between corresponding readings

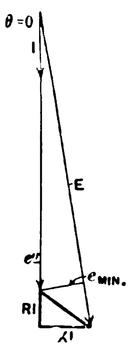


Fig. 7

Fig. 8

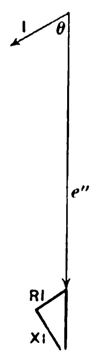


Fig. 9

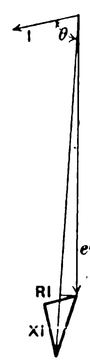


Fig. 10

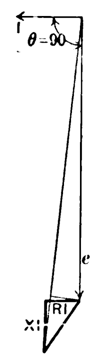


Fig. 11

of columns d and e gives the regulation pressures (column m) and as indicated by (x) in Fig. 6. Column h gives the regulation pressures by the direct method I and columns a, b, g and l furnish data for calculating regulation by method II explained above, these calculations being set down in column n and plotted as (.) in Fig. 6.

It might be of some interest to add other checks on the theory of method I. Inspecting Fig. 7, which is the transformer diagram for non-inductive load, it is evident that e_{min} practically equals $X\ I$ in value. Turning to Table I of data, first line column f, e_{min} is found to be 4.27 volts. $X\ I$, when obtained from the correct impedance triangle of method II, was found to be 4.25; a very close agreement. Again, Figs. 7 to 11 are transformer diagrams ranging from unity to zero power-factor. At unity

power-factor e'' lags behind E by a small angle α. With diminishing power-factor this angle, Fig. 8, is reduced with a corresponding reduction in the value of e_{min} until some value of power-factor as in Fig. 9 is reached, when both this angle and e_{min} have been reduced to zero and the regulation is represented by the impedance volts. With a further reduction of power-factor, Fig. 10, the angle together with e_{min} again increases with e'' now leading until another maximum displacement is reached at zero power-factor, Fig. 11, when e_{min} is but little different from the $R\,I$ drop. This variation of e_{min} is nicely indicated by the data in column f of Table I. Where its value is about zero the regulation volts should be practically the impedance volts. That such is the case the values of regulation volts of column h testify. Finally at unity power-factor the regulation is practically the $R\,I$ drop, and at zero power-factor it is as closely the $X\,I$ drop. From the data

$$R\,I^2 = 89.5 \text{ watts}$$

Hence $89.5 \div 12.56 = 7.12$, the $R\,I$ drop; where

$$\text{load current} = 12.56$$

The table gives the regulation volts for unity power-factor the value of 7.11, another agreement. Extending the curve of Fig. 5 to zero power factor we find the regulation for this point is about 4.35, which is also but little greater than the $X\,I$ drop.

Check for Accurate Adjustment of e_{min}. The consistency of the curve by method I depends, of course, upon the accurate adjustment of the pointer along the slide-wire S of transformer C. This may be checked directly by repeating an adjustment, as indeed it is desirable to do. A further check may be obtained by the use of the equation

$$e_{imp} = \sqrt{(e_{min})^2 + (e_{reg})^2}$$

That this equation is true may be readily seen by inspection of Fig. 3. If the value of the above radical corresponds closely to the value of the impedance pressure, the adjustment may be said to have been correct. Column o of the Table represents the values of this radical and the corresponding impedance pressures in column g. The agreements here are seen to be rather good,

excepting in the tenth line, where the solution of the radical, gives 8.45 while the corresponding impedance pressure is but 8.3. The adjustment here then was hardly exact, with a corresponding inaccuracy in the value of the regulation. Examining the tenth point on the curve of Fig. 5. the inaccuracy is evident. Yet even this error does not amount to much. In other words, an extremely sensitive detector of e_{min} is scarcely necessary. In the test a well damped low-reading alternating-current voltmeter was found to be good enough.

Some Further Investigations

In order to determine the source of the inaccuracy in the usual calculated method for obtaining regulation, the line e.m.f. supplying the transformers under test was gradually reduced all connections remaining precisely as before. The readings taken are given in Table II. It is here seen that the $I^2 R$ (and consequently the $I R$ drop) steadily reduces in value from 89.5 to 86.0 watts. On the contrary the impedance pressure as steadily rises in value from 8.28 to 8.5 volts. That is, as the conditions of the common short-circuit test are approached the copper loss and copper drop become less than under normal conditions of voltage (*i.e.*, normal flux density) while on the other hand the impedance of the transformer is higher in spite of the fact that the $R I$ drop is less. The difference in the two impedance triangles as found by the short-circuit test and the resistance determination, and by method II is clearly seen in

TABLE II

	a	*b*	*c*	*d*	*e*	*f*	*g*	
No.	Amp. load	Watts $R I^2$	Volts load	Volts imp.	Copper drops $b \div a$	React-ance drop $\sqrt{d^2-e^2}$	In-duced e.m.f.	Remarks
1	12.56	89.5	220	8.28	7.12	4.227	223.4	
2	"	88.5	196	8.3	7.05	4.38	199.4	
3	"	88.0	173.6	8.305	7.01	4.465	177	Load at unity
4	"	88.0	147.4	8.32	7.01	4.5	150.8	oower-factor
5	"	87.5	123.4	8.36	6.96	4.63	126.8	
6	"	86.7	94.2	8.39	6.91	4.75	97.6	
7	"	87.0	71.6	8.44	6.93	4.81	75.0	
8	"	86.7	34.9	8.50	6.91	4.95	69.2	
9	"	86.0	2.0	8.505	6.85	5.05	6.0	

Fig. 12, which applies to transformer *A* of this paper. It is observed that a difference of 20 per cent exists in the value of the reactance drop by the two methods.

The above results are shown in the form of curves in Fig. 13 the abscissas being induced e.m.f.s in all cases. The $R\,I$ and $X\,I$ curves were derived from data forming the $R\,I^2$ and e_{imp} curves. If the slightly parabolic nature of the increase of the copper watts with e.m.f. (*i.e.*, flux density) is due to more than mere chance, this increase may be reasonably supposed to be a true eddy current loss in the copper windings, increasing as the e.m.f. applied to the transformer increases. This additional $R\,I^2$ drop is, no doubt, what is vaguely referred to as "load losses" which disappear as the flux density is reduced to the conditions of the short-circuit test. On the other hand the increase of the $X\,I$ drop with a reduction of the flux density may be due to a somewhat greater permeability of the magnetic circuit. That is, assuming the same leakage magnetomotive forces at low flux densities as at high, the resulting leakage flux will be somewhat greater if the magnetic conductivity is better in one case than another. And at lower flux densities a greater permeability is expected. This, of course, assumes that a part, at least, of the leakage path is through the iron.

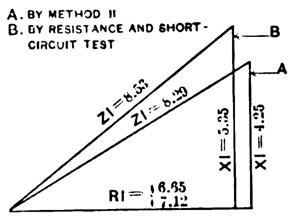


Fig. 12

Conclusions

It is evident from the foregoing that it is possible to use an accurate direct method for obtaining transformer regulation, the value being read off by a low-reading voltmeter following a simple adjustment. Only commercial instruments and apparatus are needed for the test. It is also evident that accurate data for the calculated method is readily obtainable. Both of these methods are presented with but one object in view, that of commercial utility.

Method I is intended to take the place of the ordinary direct method of reading no-load and full-load pressures. Method II is intended to substitute for the calculated methods now in use. The writer hardly thinks it sufficient to consider the older methods as amply accurate, especially when referring to calculated ones, for though a nice smooth curve may be obtained (because it is a calculated method), the truth is probably more

nearly told by the simple expedient of reading no-load and full-load pressures.

Either of the above methods should be available for the average central station and on the test floor of a transformer manufacturing company where like transformers are usually at hand.

APPENDIX

In considering the theory of method II it was assumed that the detail of calculating regulation is generally understood. But to insure this point, a brief outline is here given. Either one of two formulas may be used which lead to like results. These are as follows:

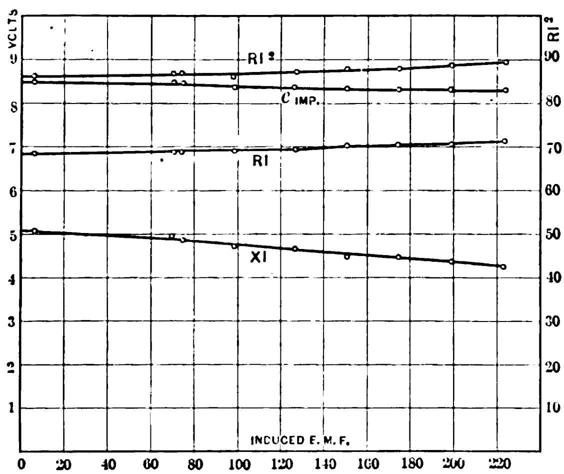


FIG. 13

$$E = \sqrt{(e'' + R\,I \cos\theta + X\,I \sin\theta)^2 + (X\,I \cos\theta - R\,I \sin\theta)^2} \quad (1)$$

$$E = \sqrt{(e'' \cos\theta + R\,I)^2 + (e'' \sin\theta + X\,I)^2} \quad (2)$$

Whereas, in the preceding text,

e'' = the secondary terminal voltage = 100 per cent.

E = the impressed voltage (reduced to terms of secondary) necessary to produce E'' under load.

$R\,I$ = equivalent resistance drop.

$X\,I$ = equivalent reactance drop.

θ = angle corresponding to power factor $\cos\theta$ of circuit.

The difference $E - e''$ is the regulation volts sought. e'' may be assumed to be the voltage stamped on the name plate of the

transformer; also θ is assumed. $R\,I$ and $X\,I$ are obtained from the solution of the data entering the impedance triangle.

Each of the above equations is based on correct theory. The first supposes the several e.m.fs. of the transformer to be resolved into components parallel to and perpendicular to e''; the second supposes them to be resolved into components parallel to and perpendicular to the current vector. In either case E is the closing diagonal.

A sample set of calculations will make clear the use of the above equations. Use will be made of the following data which refers to transformer A of this paper:

$$e_{imp.} = 8.29$$
$$R\,I^2 = 89.5$$
$$I = 12.56$$
$$e'' = 220 \text{ (name plate)}$$

Power factor $= 0.6 = \cos\theta$.

From which is derived the following:

$$R\,I = 89.5 \div 12.56 = 7.12$$
$$X\,I = \sqrt{(8.29)^2 - (7.12)^2} = 4.25$$
$$E = \sqrt{(220 + 0.6 \times 7.12 + 0.8 \times 4.25)^2 + (0.6 \times 4.25 - 0.8 \times 7.12)^2}$$
$$= 227.68 \qquad (1)$$
$$E = \sqrt{(0.6 \times 220 + 7.12)^2 + (0.8 \times 220 + 4.25)^2} = 227.68 \qquad (2)$$

Manifestly the accuracy of results depends on the accuracy of the $R\,I$ and $X\,I$ values, that is upon obtaining the values for the correct impedance triangle. The usual method of doing this is to short circuit one of the transformer windings (ordinarily the low tension) and impress a sufficient voltage on the other to allow rated full load current to flow. This gives the impedance drop and with a wattmeter inserted also the $R\,I^2$ which divided by the value of the current gives $R\,I$. Or instead of this latter, resistance measurements of both primary and secondary may be made, reduced to like terms, and added. This sum multiplied by the value of the full load current gives the $R\,I$ drop, and

$$X\,I = \sqrt{(\text{Imp. volts})^2 - (\text{R I})^2}$$

It must be remembered that the data by this method is obtained under conditions of low flux density and hence the discrepancy when compared with method II presented in this paper.

NOTE

The following paper is to be read at the 27th Annual Convention of the American Institute of Electrical Engineers in **Jefferson, N. H., June 28 - July 1, 1910.** This paper is to be presented under the auspices of the Railway Committee of the Institute. All those connected with the Institute and desiring to take part in the discussion of this paper may do so by being present at the meeting; or, if this is not possible, by sending in a written contribution.

Written contributions will be read at the meeting, time permitting, for which they are intended, either in full, in abstract, or as a part of a general statement giving a summary of the views of those taking the same position in the matter.

The principal object in getting out the paper in advance of the meeting is to enable and encourage those not in a position to attend the meetings to take part in the discussion by mail.

Contributions to the discussion of this paper should be mailed to **William McClellan, Chairman Railway Committee, 905 West Street Building, New York,** so that they will be received not later than June 23, 1910. Written contributions arriving within 30 days thereafter will be treated as if presented at the meeting.

(HARRIS)

A paper to be presented at the 27th Annual Convention of the American Institute of Electrical Engineers, Jefferson, N. H., June 28–July 1, 1910.

(Subject to final revision for the Transactions.)

A METHOD FOR DETERMINING THE ADEQUACY OF AN ELECTRIC RAILWAY SYSTEM

BY R. W. HARRIS

The adequacy of a railway system is often a point of contention between the public and the company. The many lawsuits and investigations carried on by various regulating bodies is evidence of this fact, and such cases are always a source of trouble and expense. In many instances they are unnecessarily brought about by "chronic kickers" who take advantage of every opportunity to gain political popularity through an attack on the railway company for lack of cars, unreliability of service, etc. The answers to such complaints are generally so indefinite and technical that the ordinary layman finds it difficult to obtain a satisfactory explanation and understanding. Consequently, there is a continual complaint and disturbance among the traveling public because, perhaps, of alleged insufficient accommodation and the lack of a fair knowledge of the railway business.

As a matter of fact, companies often do not know definitely whether or not their systems are really serving the public in the best possible way. A necessary requisite of successful operation is to satisfy as conveniently as possible the requirements of the public that are established by a natural development of the community. The petty whims and fancies of the few are not serious factors in determining the adequacy. There are, however, certain habitual movements (barring a certain amount of indiscriminate travel by pleasure seekers, shoppers, etc.) which the traveling public forms that are comparatively stable in character and magnitude. They are the natural resultant of the various routes automatically established by the

passengers. These movements occur daily and, in general, do not fluctuate in direction, for when the habit of making a "usual" trip over a certain route is once formed, it is seldom broken.

Every city has its manufacturing, wholesale, retail, and residence districts definitely located and these are changed only very gradually through years of growth and development. Consequently, the origins and destinations, except in a few cases, will not change materially.

The extent to which these prevailing movements are met is an important index of the adequacy of a railway system. Adequacy involves many delicate and technical questions of a more or less intangible nature. The extreme fluctuations in the amount of travel caused by different weather conditions, etc., make it impossible, as well as impracticable, to endeavor to meet all peak conditions of travel with satisfaction to all.

It is the purpose of this paper to bring out certain conditions which were encountered while making an investigation into the adequacy of The Milwaukee Electric Railway & Light Company's railway system for the Railroad Commission of Wisconsin, under the direction of the author, and to show how they were considered.

If a system is adequate, it must be sufficient to care for the reasonable demand of the traveling public in its various forms as well as to be in line with a well directed plan to care for present and future business economically. The routing of the cars that serves the largest number of people by the most direct route, at times when the traffic requires it, free from delay and with a sufficient number of sanitary cars so the average amount of traffic will be comfortably cared for, is highly desirable. These are very material factors in establishing an adequate system. A failure to provide any one of these accommodations will result in an attack, sooner or later, on the company for giving poor service. In most cases the conditions become exaggerated in the minds of the public through the lack of sufficient understanding of the business and, as a result, the company may sacrifice a part of the public's good will.

A system that satisfies the above requisites, carried to such an extent that the amount of investment required and costs incurred will not exceed a reasonable proportion of the earnings as well as to be a convenient link in a systematic plan arranged to care for future growth of business, might be said to be an adequate system.

The particular layout of a city and the franchises that may be secured enters the case to such an extent that it is often impossible to establish a direct route for all classes of passengers. These, together with many other difficulties, may make it impossible to secure an adequate system in the strictest sense of the term. An adequate system, from a practical point of view, is one that will handle the demands of the public in the shortest time by the most direct route with as little distortion of headway as possible, and with the least inconvenience to the passengers. Reliability of service is necessary. If the regular headway is frequently distorted to such an extent that the public suffers from the lack of regularity in the service, the system is inadequate, since it does not supply the reliability characteristic. The nature of these various conditions are radically different, and are peculiar to each city. Each company must study its own characteristics of service and determine its own method of handling various conditions. There is very little reliable data to be had regarding the detailed features of service. However, considerable has been written regarding general conditions in various localities.

The data and curves shown in the following pages are not the result of a theoretical deduction but are compilations of data taken by a trained force of inspectors along a definite, pre-arranged outline so designed as to show the various conditions as they exist in the system's operation. All data were observed on the street and compiled so as to show clearly the features of operation. No dependence has been placed upon any records of the company that were obtained in the form of trip sheets, and general data collected by supervisors, etc. The effects of numerous personal elements of the uninterested trainmen, who so often fail to appreciate the importance and use of such information, do not enter.

A general study of the movement of people during the day revealed the fact that there were four distinct periods during which the majority of people travel. These periods were very easily determined, for during such times the amount of travel was much greater than that during other portions of the day. They were designated arbitrarily as Period No. 1, Period No. 2, Period No. 3 and Period No. 4, and were found to occur, respectively, from 6:00 a.m. to 9:00 a.m.; 11:00 a.m. to 2:00 p.m.; 5: p.m. to 8:00 p.m.; and 10:00 p.m. to 11:00 p.m.

The adequacy of the system will be measured by the con-

ditions existing during these periods since all features of traffic will be encountered in their greatest degree of effectiveness. The rate of flow of passengers, so to speak, resulting in the largest demand for cars, is greatest during these periods as well as the amount of congestion in the down town districts, all of which are material factors in distorting headway. During these periods, certain classes of passengers are easily agitated and become abusive to the company on account of inconveniences experienced due to late cars, overcrowding, etc. This feeling becomes intensified with any neglect on the part of the company to rectify and improve such conditions.

A careful investigation of each line and a determination of the characteristics during the peak periods are the first requisites that lead to a definite measure of adequacy.

A definite plan was outlined for conducting a study of the system that would determine the practical working conditions as mentioned above, and so arranged that all similar observations made by the inspectors would be on the same basis. Each inspector was assigned a line to observe and was directly responsible for securing accurate and reliable data. He made a preliminary study of the line with a view of locating the principal points where the most people boarded and left the cars. These were selected as points of observation. A sufficient number of points were chosen for each line that would give the main characteristics. As a rule, from 6 to 14 or 15 points were selected, depending upon the traffic of the line.

The following data were observed for all cars on each line going in each direction, at all points of observation, and throughout each period, with possibly a few exceptions. This method required the inspector to spend practically a day at each point. As a matter of fact, however, his time was distributed along the line so as to give characteristics that would embody the various conditions occurring during a long period of time:

Time car arrived at point of observation.
Direction car is going.
Number on car body.
Total number of passengers.
Total number of passengers in front vestibule.
Total number of passengers in car body.
Total number of passengers in rear vestibule.
Number of passengers leaving car.
Number of passengers boarding car.

Class of passengers.
Conditions of vehicular traffic.
Conditions of pedestrian traffic.

All data could be obtained by count or close estimates excepting the class of passengers and condition of vehicular and pedestrian traffic. These were recorded according to the following arbitrary scheme:

Passengers.

1st class—Professional and business people.
2nd class—Clerks and shoppers.
3rd class—Laborers.

Vehicles and Pedestrians.

1st condition—Few in number.
2nd condition—Considerable amount but not enough to cause delay.

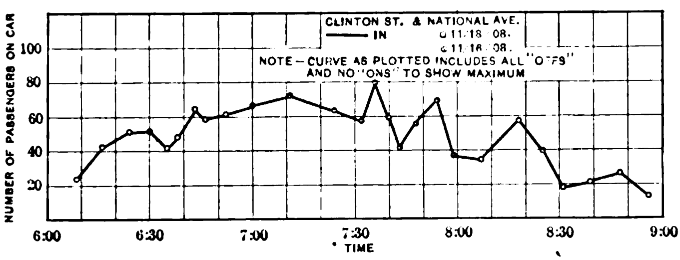


FIG. 1.—Fluctuations of traffic—Oakland-Delaware line (south end) Period 1

3rd condition—Sufficient amount to cause much delay to cars.

At first glance it might seem that the amount of data to be taken of each car going in each direction is more than could be expected without sacrificing accuracy, and especially when the time spacing of cars is often as short as ten seconds; this feature, however, is overcome by practice in making observations. As a matter of fact, the inspectors became so efficient that the data was found to be 95 per cent accurate by test, which is sufficiently close for this class of work. This data does not embody sufficient information to establish all characteristics of the lines and it was found necessary to obtain various miscellaneous data of a general character. This general investigation was made of each line by the inspector to supplement the detailed data which had been secured by the service inspection.

Considerable time was spent in observing the operation of the line and its surroundings in a casual way with a view of determining any special features of the line that were characteristic of all lines, as well as those that were more or less local. The following gives an outline of the data required of the inspector in making the general report of his line:

(a) Divide line into characteristic sections (bound each roughly) and discuss each as to class of passengers, time of travel and probable destination.

(B) Locate various origins of passengers along line, obtain as closely as possible their destination and probable route. (Refer to factories, etc).

(c) State transfer points and give an idea as to the number (in percentage of passengers leaving car from which transfer is made) transferring to other lines (name the lines) in various directions.

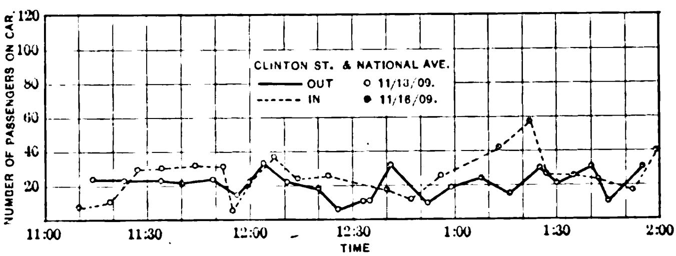


FIG. 2.—Fluctuations of traffic—Oakland-Delaware line (south end)—Period 2

(c) Determine the attitude of the public served by the particular line as regards the service given by the company. This can be done by several casual conversations with passengers.

(e) Make a few specific observations (record count) of the movement of the passengers (seated passengers to vestibule and vice versa) in the car as it approaches the stop in downtown and outlaying districts.

(A few continuous trips through the districts under investigation during the various periods will probably give the information desired.)

The above included a general reference to the transferring question but, on account of the impossibility of determining the number of people leaving or boarding the car who hold transfers, this data had to be supplemented by a study and classification of the transfers actually collected by the company

(Fig. 11). On account of the endless amount of work thus involved, it was considered advisable to classify the transfers taken on a representative day and qualify this information by that secured in the general report.

An investigation of the headway that existed in the various districts along the lines is embodied in the requirements of the detailed study. For the sake of comparison and assistance in determining what was the safe minimum time spacing of cars for any section of track, certain observations were made in various cities in the middle west where conditions were somewhat similar to those found in Milwaukee. The result of these observations are shown in the following pages.

The above gives a general idea of the method used to secure the field data. There are, however, many minor details omitted that perhaps would be of interest but, for the sake of brevity,

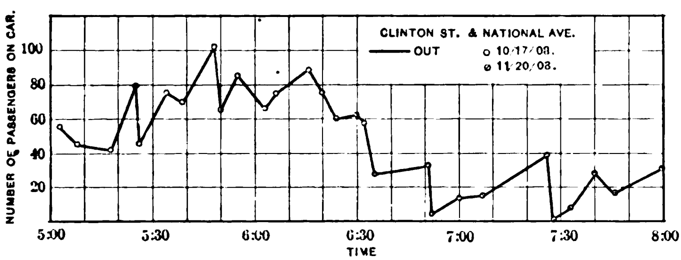


FIG. 3.—Fluctuations of traffic—Oakland-Delaware line (south end)—Period 3

they are left to be inferred from the various tables, curves, etc.

While there was a marked difference in the amount of traffic during the various periods of maximum travel, as compared with other times of the day, yet the traffic was, by no means constant during any period. As a matter of fact, the traffic during one portion would be radically different from that of other portions of the same period. Fig. 3 gives an example of the curves showing the fluctuation of traffic during the periods of maximum travel with time as one axis and total number of passengers as the other. The most characteristic point of each line was selected and a similar traffic fluctuation curve plotted. These curves show a very pronounced difference in the amount of travel between practically two parts. A reference to Fig. 3 shows a maximum period from 5 p.m. to 6:30 p.m. and a minimum period from 6:30 p.m. to 8 p.m.;

TABLE I. SUBDIVISIONS OF PERIODS OF CONGESTION FOR VARIOUS LINES

Line	Place	Period I 6 a.m. to 9 a.m. Maximum sub-period	Period I Minimum sub-period	Period II 11 a.m. to 2 p.m. Maximum sub-period	Period II Minimum sub-period	Period III 5 p.m. to 8 p.m. Maximum sub-period	Period III Minimum sub-period	Remarks
1. Wells-Farwell	Jackson & Biddle	7:30–9	6–7:30	11:40–12:40 12:45–2	11–11:40 12:40–2 11–12:45	5–6:30	6:30–8	E. End-Out E. End In
Wells-Farwell	11th & Wells	6–8	8–9	12:45–2	11–12:45			W. End Out
		7:30–8:30	6–7:30		11–11:45			
			8:30–9	11:45–12:45	12:45–2	5–6:30	6:30–8	W. End In
2. Fond du Lac-National	Walnut & Third	6–8	8–9	11–2		5–7	7–8	North End
3. Walnut-National	Reed & National	6–7	7–9	11–2		5–6:30	6:30–8	So. End Out
		7–9	6–7	11–2		5–6:30	6:30–8	So. End In
4. 8th Ave.-3rd St.	Reed & Greenfield	6–8	8–9	11–2		5–6:30	6:30–8	South End
4. 8th Ave. 3rd 5. Burnham-3rd	North Ave. & 3rd St.	6–8	8–9	11–2		5–6:40	6:40–8	North End
5. Burnham-3rd St.	Reed & National	6–8	8–9	11–2		5–6:30	6:30–8	South End
6. Oakland-Delaware	Clinton & National	6–8	8–9	11–2		5–6:30	6:30–8	South End
Oakland-Delaware	Brady & Astor	6–9		11–2		5–6:30	6:30–8	North End
7. Holton-Mitchell	Clinton & National	6–8	8–9	11–2		5–6:30	6:30–8	South End
Holton-Mitchell	E. Water & Wisconsin	6–8	8–9	11–2		5–6:40	6:40–8	North End
8. Muskego-8th St.	3rd & State	6–8	8–9	11–2		5–6:45	6:45–8	North End
Muskego-8th St.	Reed & National	6:30–8	6–6:30 8–9	11–2		5–6:30	6:30–8	South End
9. Clybourn-Wisconsin	Grand & 6th	6–7	7–9	11–2		5–6:20	6:20–8	
10. Twelfth-Wisconsin	Wells & 11th	6–8	8–9	11–2		5–6:45	6:45–8	
11. State-Wisconsin	State & 3rd	7–9	6–7	11–2		5–6:30	6:30–8	
12. Vliet-First Ave.	Reed & Greenfield	6–8	8–9	11–2		5–6:30	6:30–8	South End
Vliet-First Ave.	Third & Chestnut	6–8	8–9	11–2		5–6:30	6:30–8	North End
13. Vliet-Howell	Reed & Greenfield	6–7:45	7:45–9	11–2		5–6:30	6:30–8	South End
Vliet-Howell	Third & Chestnut	6–8:20	8:20–9	11–2		5–7	7–8	North End
14. North Ave.	North & Twelfth	7:15–7:45	6–7:15 7:45–9	11–2		5–6:30	6:30–8	

these are termed " maximum sub-period " and " minimum sub-period ", respectively. This feature prevails throughout period No. 1 and Period No. 3, occurring practically at the same time for all lines (see table 1.) During Period No. 2 this characteristic is not so prominent and, on account of the comparatively small amount of travel, it was considered unnecessary to sub-divide

TABLE II. SUMMARY OF PASSENGER DATA MUSKEGO EIGHTH STREET LINE

Period	Sub-period	Place	Direction	Ave. No. people		Ave. No. of		Ave. No. pass. on		Ave. No. pass.	
				on car	in car body	vacant seats	pass. stdg.	front vest.	rear vest.	on	off
3	5–6:45	8th & North	N(out)	55^{26}	44^{26}	—	2	5^{22}	9^{23}	2^{26}	4^{26}
3	6:45–8	"	"	32^{13}	25^{13}	17	—	3^{8}	6^{10}	2^{13}	4^{13}
3	Ave.	"	"	48^{39}	38^{39}	4	—	4^{30}	8^{33}	2^{39}	4^{39}
3	5–6:45	7th & Walnut	"	69^{28}	54^{28}	—	12	6^{27}	10^{28}	4^{28}	2^{28}
3	6:45–8	"	"	37^{9}	30^{9}	12	—	3^{7}	6^{8}	5^{9}	1^{9}
3	Ave.	"	"	61^{37}	48^{37}	—	6	5^{34}	9^{36}	5^{37}	2^{37}
3	5–6:45	7th&Chestnut	"	70^{26}	54^{26}	—	12	6^{25}	10^{26}	3^{26}	1^{26}
3	6:45–8	"	"	38^{9}	32^{9}	10	—	3^{6}	4^{9}	3^{9}	1^{9}
3	Ave.	"	"	61^{35}	48^{35}	—	6	6^{31}	9^{35}	3^{35}	1^{35}
3	5–6:45	3rd & State	"	63^{26}	52^{26}	—	10	5^{16}	7^{22}	5^{26}	0^{26}
3	6:45–8	"	"	27^{10}	24^{10}	18	—	3^{5}	4^{4}	2^{10}	1^{10}
3	Ave.	"	"	53^{36}	44^{36}	—	2	4^{31}	6^{26}	4^{36}	0^{36}
3	5–6:45	3rd & Grand	"	59^{26}	46^{26}	—	4	5^{23}	8^{25}	16^{26}	1^{26}
3	6:45–8	"	"	21^{9}	18^{9}	24	—	3^{4}	2^{8}	9^{9}	2^{9}
3	Ave.	"	"	49^{35}	39^{35}	3	—	5^{27}	7^{33}	14^{35}	1^{35}
3	5–6:30	Reed & Nat'l.	N(in)	16^{14}	15^{14}	27	—	2^{4}	2^{5}	4^{14}	1^{14}
3	6:30–8	"	"	19^{10}	15^{10}	27	—	2^{6}	4^{6}	1^{10}	1^{10}
3	Ave.	"	"	17^{24}	15^{24}	27	—	2^{10}	3^{11}	3^{24}	1^{24}
3	5–6:30	11th&Green'f	"	11^{13}	9^{13}	33	—	2^{5}	4^{2}	1^{13}	0^{13}
3	6:30–8	"	"	10^{16}	9^{16}	33	—	2^{6}	2^{5}	2^{16}	0^{16}
3	Ave.	"	"	11^{29}	9^{29}	33	—	2^{11}	2^{7}	1^{29}	0^{29}

it. Incidentally, these curves give a slight idea of the headway as it actually occurred.

The detailed observations were classified, compiled, and arranged according to these sub-periods as shown, for example, in Table 2. These results show an average of several observations during a sub-period at any point of observation. For the sake of a correct interpretation of the data, the number of observa-

tions upon which each average is based is shown by an exponent. These averages are plotted and form a basis for the " car demand curve ", Fig. 4, one axis of which is the number of people on the car while the other represents the line in question drawn to scale and shown as if the route were straight. Separate curves were plotted for each sub-period as well as for the entire period and arranged so the same vertical axis is common to all, but with the horizontal axis so placed that the curves could be easily compared. On account of period No. 4 being the theater period, during which the traffic is more or less local, investigation into its characteristics was confined to a general study. Practically all the characteristics of this period were found to be effective, to a general degree, in Periods No. 1, 2 and 3. For this reason it was considered that any scheme sufficient to meet the requirements of the other periods would satisfy those of Period No. 4. Hence, no further investigation was made.

The average number of people on the car for that particular period or sub-period was plotted and represents the average number of people arriving at that particular point of observation. Through this point, and parallel to the horizontal axis a line is drawn of such length as to represent the average number of people leaving the car. From the extreme left end of this another line is drawn, superimposed upon the former, of such a length as to represent the average number of people boarding the car at this point. The right end of this line then represents the average number of people on the car as it leaves the point of observation. This point was then joined by a straight line to the point representing the average number of people arriving at the next point of observation. The slope of the line joining any two points represents approximately the resultant of the various changes of load through the intervening territory.

The diagram at the left is drawn to scale and represents the class and extent of territory served by the line in question. The information upon which the classification of territory is based was obtained from the general report mentioned in previous pages and later outlined on the map, Fig. 5, after which that portion served by each line, either alone or in conjunction with other lines, was shown by the respective car-demand curve.

These car-demand curves show, at a glance, the principal characteristics of the line, the time, amount and duration of travel, origin of passengers, as well as their destination; and, by reference to the "district diagram," the class of people and

extent of territory served, can be seen. The average number of people boarding and leaving the car at any point of observation as well as the general tendency of the load to increase or decrease in a certain territory, is also shown. All these facts have a

FIG. 5.—Routing of the Milwaukee Electric Railway & Light Company's lines

very material bearing upon the adequacy. A little study of the conditions, in connection with the general layout of the system, gives a definite idea as to whether or not the passengers are carried over a direct route to their destination.

The adequacy, however, is not fully determined until the number of cars in service is compared with the demand for cars. By associating the curve with the number of observations upon which the car averages are based, an idea of the average number of people carried can be had.

The number of cars per hour required depends naturally upon the number of people to be carried as well as the number that can be carried by one car. The number of people that can be carried, under average conditions, with comfort to all, or the "comfortable load" as it may be called, is equal to the seating capacity of the car plus the number that will be willing to stand by preference. It is to be understood that the comfortable load is not the maximum allowable load a car should carry but is that which, under average conditions, will comfortably accommodate the passengers. The rate of flow, so to speak, of the traffic is entirely beyond the control of the company and very often is such that the cars become unexpectedly overcrowded. Such conditions are likely to occur at any time, and often when least expected. No practical arrangement or schedule can be devised that will provide comfort under all conditions to every one.

Fig. 6 shows the result of the classification and averaging of approximately 9000 observations, and gives accurate information regarding the number of people who are willing to stand of their own accord for various degrees of loading. The horizontal axis represents the degree to which the car is loaded while the vertical axis represents the average of all observations made for any particular load. The number of observations upon which each average is based is given.

The average seating capacity of a Milwaukee city car is 42. A reference to the curve shows that eight people are willing to stand when the car is loaded with 42 people. Considering the vast number of observations made and the consistent curve obtained by plotting the averages for the different degrees of loading, it is reasonable to believe that there exists a well grounded law regarding the average proportion of a load which will be willing to stand by preference. It is reasonable to believe that eight is a consistent number for this degree of loading. Hence, the comfortable load will be 50 people. A line drawn through 50 on the horizontal axis of the car-demand curve, parallel to the vertical axis, establishes a reference line. From this it is easily seen through what territories, at what times,

the direction of travel, and the amount that the line is inadequate from a service point of view. A measure of this inadequacy, during any period of maximum travel, can be readily seen by observing the average number of people who are forced to stand through the territory, multiplied by the average number of cars used, and this divided by the comfortable load. This gives the number of additional cars required. The averages referred to, however, are not necessarily arithmetical averages of the numbers shown on the curve, but are such as represents a fair figure for the particular territory when the conditions,

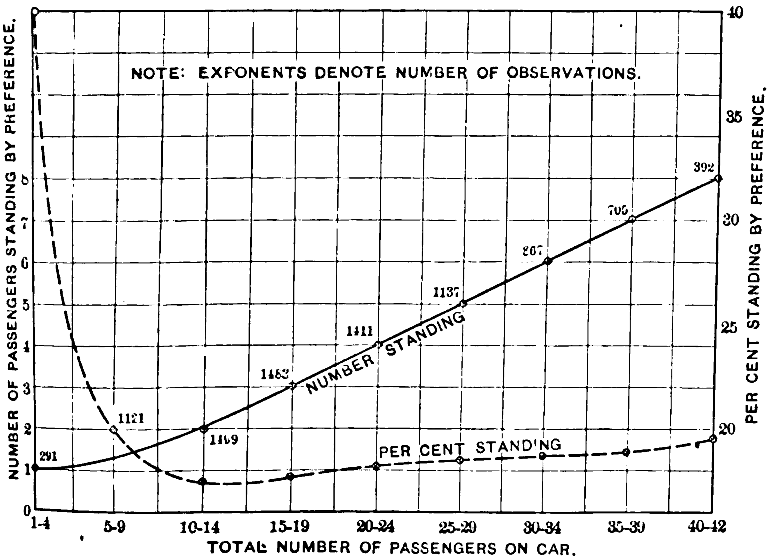


FIG. 6.—Number and percentage of passengers standing on cars by preference

as shown by the curve, are modified by local features and good judgment.

The scheduled headway, or time spacing of cars, is scarcely, if ever, effective, to any degree of certainty during any great length of time, for many reasons, as for example, delay due to railroad crossings, opening of bridges, exceptionally heavy vehicular traffic, delay of other cars, slippery tracks, and other operating features that are continually fluctuating and uncertain in character. It must be considered, in the design of any schedule, that the headway should be such that with the amount of distortion which usually exists it would not be less (fewer

seconds) than a certain safe minimum amount. This minimum time spacing of cars may vary for different places where a different combination of conditions is in existence. It is the determining factor that fixes the "full load" capacity of that section of track.

The following is the method used in determing the safe minimum headway at which cars can be operated on Grand Avenue near Third Street, where double tracks crossing double tracks are used in connection with one pair of opposite quadrants one more than the other. All figures are based upon accurately observed data taken in Milwaukee and compared with similar observations made in other cities. (Table 6).

In determining the safe minimum headway from data observed in the field, the basic elements were considered separately:

A. The minimum safe practicable time spacing of cars when in continual motion unaffected by any delay.

B. The average amount of delay of any given car due to causes arising from other cars operated over the same or intersecting tracks.

C. The average amount of delay due to causes having their origin within the car under consideration.

Specific observations were made of the above elements the results of which were shown on the various tables. The results of the basic elements embodied in group *A* are given in Table 3 by which it is shown that the average safe minimum time spacing between consecutive cars, under these conditions is 8.3 seconds for 49 observations, taken during the congested period. In calculating this table, allowance was made; first, for the space covered in one second at full speed to allow the train crew to act; second, for the distance required to stop the car at the observed speed with an assumed negative acceleration of 1½ miles per second; third, for a clear space of 15 feet between cars when stopped.

Group B and C Elements. Conditions which may cause delay to the movement of the cars in one direction under conditions found at Third St. and Grand Ave. are:

(*a*) Car ahead going in same direction upon approaching the intersection but taking the curve.

(*b*) A car taking curve in nearest quadrant but resulting in going in the opposite direction.

(*c*) One car crossing at right angles.

(*d*) Two cars crossing at right angles but going in opposite directions.

TABLE III. TABLE SHOWING TIME SPACING OF CARS AT THIRD STREET AND GRAND AVENUE AS AFFECTED BY GROUP A ELEMENTS
(Time of stops and intersections is not considered here)

Observations taken during	Length of car	Safe space between cars when stopped	Observed speed ft. per sec.	Miles per hour	Distance car travels after braking ft.	Safe minimum spacing ft.	No. of cars passing a given point per hr.	Headway (Time spacing of cars) seconds	Remarks
Congested period	41′	15′	12.27	8.4	34.22	102.49	433	8.3	Average 49 observations
Non-congested period	41	15	14.26	9.73	45.76	116.02	433	8.1	Average 36 observations
Congested period	41	15	13.34	9.11	40.44	109.78	438	8.2	Av. frequency of cars for congested period
Congested period	41	15	16.90	11.53	61.80	134.70	452	8.0	Frequency somewhat decreased
Congested period	41	15	8.05	5.50	14.73	78.78	368	9.8	Much delay

(*e*) Regular service stops.
(*f*) Unusual vehicle and pedestrian traffic.
(g) Delay due to hesitancy of motorman and supervisor.
(*h*) Delay due to hesitancy of cars approaching switches before taking curves.
(*i*) Any other conditions:

Observed Data Relating to Above Conditions.

TABLE NO. IV

Date of observation	Period of traffic	Time of count	(1) Total No. of cars approaching curves	(1) Total No. of cars taking curve	Per cent (2)/(1)	Remarks
11/21/08	1	7:00–8:00 a.m.	55	17	30.9	Ordinary conditions of peak traffic
11/20/08	2	12:00–1:00 p.m.	54	16	33.8	Same as above
11/20/08	3	5:15–6:16 p.m.	91	31	34.1	Maximum conditions of peak traffic

(*a*) Since the problem resolves itself into safe operation for maximum conditions, it is advisable to use those as found in Period No. 3, or 34 per cent.

(*b*) Conditions same as (*a*), for as many cars take curve at Third St. and Grand Ave. going north as those that take curve from north going east, or 34 per cent.

(*c*) Data on cars crossing at right angles.

Date of observation	Period of traffic	Duration of count	(1) Total cars crossing going west	(2) Total cars crossing going north	(3) Total cars crossing going south	(2) + (3)	Per cent $\frac{(2)+(3)}{(1)}$
1/13/09	3	5:15 to 6:15p.m.	68	68	59	127	187*
(Congested cars taking curves not considered).							
1/11/09	Between 1&2	10:03 to 11:03a.m	39	36	35	71	182*
(Non-congested cars taking curves not considered).							

NOTE:* Relation (in per cent) of cars on two tracks to those on one intersecting track during the given interval. This percentage is here used as a measure of the tendency to interruptions.

(*d*) Two cars crossing at right angles but going in opposite directions. Approximately 10 per cent of total cars make a straight intersection.

(*e*) Regular service stop; may be made by any car (100 per cent).

(*f*) All cars are submitted to usual vehicle and pedestrian traffic (assume 10 per cent).

(*g*) Approximately 50 per cent of all cars are delayed, due to hesitancy.

(*h*) About 75 per cent of all cars taking curves are delayed on entering curves.

(*i*) Any car may be delayed approximately two seconds for other reasons.

NOTE: It should be remembered that each of the above elements (*a*) to (*i*), inclusive, relates to interruptions caused by a preceding or intersecting car.

TABLE 5. DETERMINATION OF THE COMPOSITE DELAY DUE TO GROUPS B AND C ELEMENTS
(By weighted averages)

Cause or condition	Per cent of cars affected as observed	Seconds delay	Seconds × per cent
a	34%	15.4	523.6
b	34	15.4	523.6
c	187	9.9	1851.3
d	10	13.0	130.0
e	100	15.2	1520.0
f	10	8.0	80.0
g	50	5.0	250.0
h	75	5.0	375.0
i	100	2.0	200.0
Total	600		5453.50

Weighted average delay for 1 per cent of cars observed is 9.09 seconds.

As shown in table 4 the number of cars actually observed was 91 and is represented by 100 per cent in the above table. From this the composite delay due to the causes listed under groups *B* and *C* is 9.99 seconds, or 10 seconds.

The minimum safe practicable headway is, therefore, 8.3 plus 10 seconds, or 18.3 seconds. By a comparison and interpretation of data obtained in various other similar cities (Table 6) it is considered that the operating speed in Milwaukee is somewhat faster than that of other cities. For this reason a minimum safe practicable headway of 20 seconds is more conservative. It will permit a maximum of 180 cars per hour to pass a given point in one direction with safety. A comparison of this minimum safe

headway and the headway in operation on Grand Ave., near Third St.,(see Fig. 7) gives an idea as to the adequacy of this section of track. Forty-eight cars out of 197, or 25.4 per cent, were operated at a headway which, under favorable average conditions, is equal or less than the safe minimum time spacing. If there is no possible way of reducing the amount of distortion, and the same scheduled headway is required as shown by the car demand curves, then this section is inadequate for the lines. A re-routing scheme, therefore, becomes necessary. The adequacy of any section of track, from a safety point of view, can be determined in a similar way.

The average actual headway of the various lines in the down town district for periods No. 1 and 3 is approximately 6 minutes,

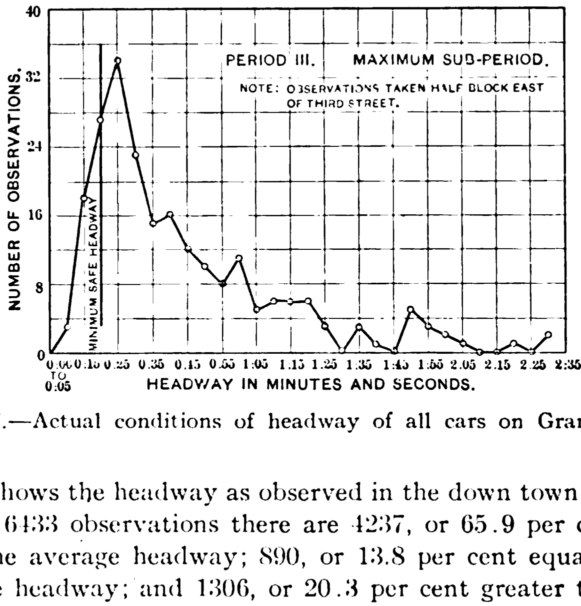


FIG. 7.—Actual conditions of headway of all cars on Grand Ave.

Fig. 8 shows the headway as observed in the down town district. Out of 6433 observations there are 4237, or 65.9 per cent less than the average headway; 890, or 13.8 per cent equal to the average headway; and 1306, or 20.3 per cent greater than the average headway.

In other words, then, 20.3 per cent of the cars, so to speak, are inconveniently spaced from a point of view of reliability. Since this amount is made up of spacings above 6 min., and range in length up to 20 min., some idea can be obtained as to the reliability characteristic of service.

As hinted before, this distortion may be due to causes which cannot be controlled but there are, however, certain environments that can be influenced with proper care on the part of

the company and assistance on the part of the passengers. A very important condition effecting headway is the time required for service stops. The stop should be made at a definite point suitable for all conditions of travel thereby reducing the amount of confusion caused by passengers boarding and leaving the car. The rate at which the passengers board and leave cars, together with other minor conditions, practically determines the length of service stops. Figs. 9 and 10 show the results of an investigation made in various cities by which the fact is brought out that Milwaukee traffic is much slower than that

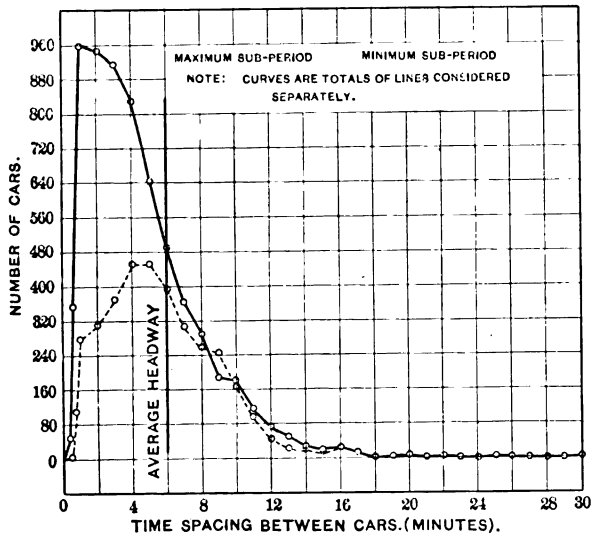


FIG. 8.—Time spacing of cars as observed at principal points—Period 1 and 3

in other cities, especially when a large number of people desire to board or leave the car. In fact the Milwaukee traveling public is practically 25 per cent slower than that found in St. Paul, Minneapolis, Duluth, Indianapolis and St. Louis. It is to be noted that practically identical curves were obtained by plotting data observed in Milwaukee on different days.

The use of properly worded signs, etiquette on the part of the employees, as well as a little coöperation by the public, etc., are necessary to reduce the distortion of headway which results in an increase of the reliability of service.

The author has endeavored to bring out, in a very general way

a method for determining the amount of service given by a railway system as well as to show an example of a method for showing the requirements of the public in a spe-

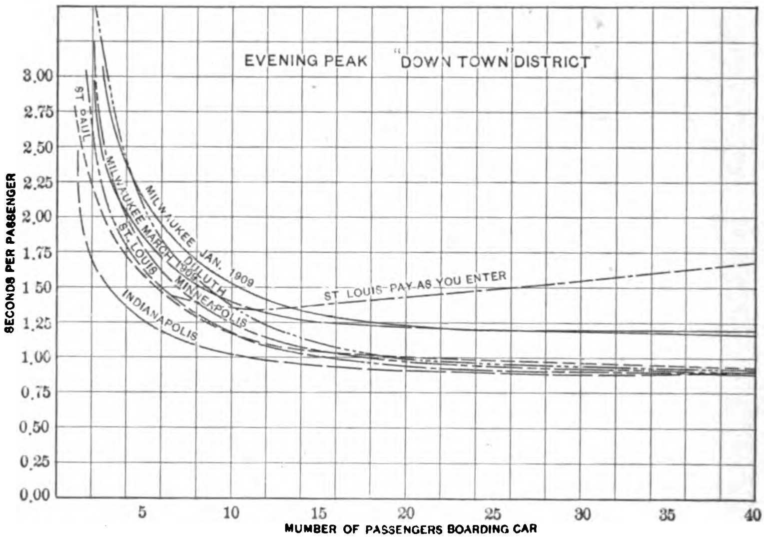


FIG. 9.—Movement of passengers boarding cars

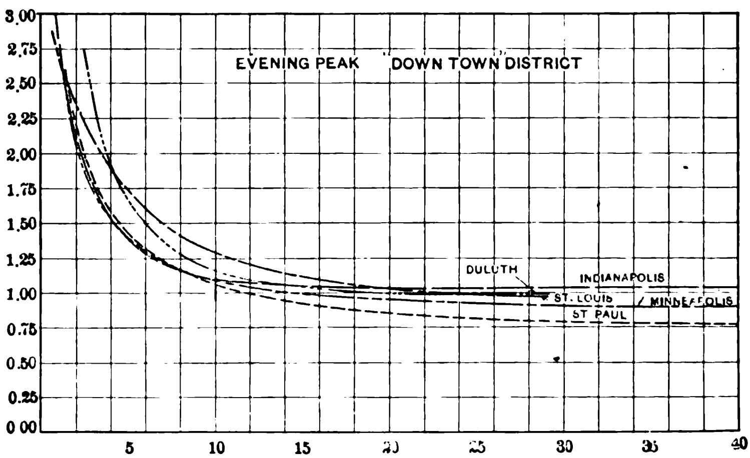


FIG. 10.—Movement of passengers leaving cars

cific case. A correct knowledge of the various conditions mentioned above is an invaluable asset to the company's operating data both with a view to satisfying the demand of the public

as well as a check on the economical features of operation and investment.

No attempt has been made to show the method of arriving at a satisfactory schedule; however, the time, direction and amount of travel are shown on the car demand curves. It has not been the object to determine what is an economical "yearly load factor" for the cars or the relation this load factor bears to the investment required. The author has made a special study of these features but on account of their importance and length of discussion involved they are not embodied in this paper. The data and description contained in the foregoing pages represents observed conditions regarding a special case where only surface lines are operated and is given with a view of bringing out a discussion that will afford many suggestions which will aid in determining the amount of service necessary to care for any given demand.

TABLE 6. DATA SHOWING AVERAGE SPEED AND TIME FOR MAKING INTERSECTIONS AS OBSERVED IN ACTUAL OPERATION IN VARIOUS CITIES

I. Speed Observations.

(a) Congested period.

	No. of observations averaged	Feet per second	Miles per hour	Remarks
Milwaukee conditions........	49	12.27	8.4	
Indianapolis "	28	13.00	8.86	
St. Louis "	7	8.65	5.9	Av. peak conditions
	1	4.6	3.1	Blocked
	4	12.45	8.5	Cars moving freely
	12	9.58	6.54	Total average
Minneapolis "	30	9.08	6.2	
St. Paul "	26	14.14	9.65	
Duluth "	31	12.51	8.53	
(*b*) Non-congested Period				
Milwaukee conditions	36	14.26	9.73	
Indianapolis "	15	16.01	10.93	
Minneapolis "	31	14.91	10.16	
St. Paul "	30	19.27	13.13	
Duluth "	30	13.40	9.13	
(*c*) Miscellaneous speed observations to show effect of a few causes of delay.				
Milwaukee conditions...........	6	13.34	9.11	Average frequency and free movement of cars
	3	16.90	11.53	Frequency decreased. Free movement of cars.
	1	8.05	5.50	Much delay.

II. Intersection and Curve Observations.

(*a*) Congested Period.

One car making a straight intersection (from the time the front end of car passes over switch frog until rear end is clear of second crossing track).

	Number of observations averaged	Seconds
Milwaukee conditions.............	26	9.9
St. Louis "	14	9.2
Indianapolis "	10	10.3
Minneapolis "	28	10.6
St. Paul "	15	7.8

Two cars making a straight intersection, but going in opposite directions (from time front end of first car blocks traffic until last car clears).

Milwaukee conditions..................	15	13.0

Two cars taking curves of same quadrant, but going in opposite direction (from time first car enters curve until curves are cleared).

Milwaukee conditions.............	15	18.8
Indianapolis "	9	12.3

One car taking a curve (time front end of car enters curve until rear end clears curve).

Milwaukee conditions.............	22	15.4	
St. Louis "	6	7.2	City cars
	3	16.8	Suburban cars
Indianapolis "	13	11.4	
Minneapolis "	7	14.3	
St. Paul "	14	10.8	
Duluth "	13	8.8	

One car taking a curve with one car making an intersection resulting in both cars going in same direction (from time front end of first car blocks traffic until last car clears).

Milwaukee conditions.................	5	14.7

(*b*) Non-congested period.

One car making a straight intersection (from the time the front end of car passes over switch frog until rear end is clear of second crossing track).

	Number of observations averaged	Seconds
Milwaukee conditions.............	28	10.0
Minneapolis "	21	8.4
St. Paul "	18	7.9

One car taking a curve (time front end of car enters curve until rear end clears curve).

Milwaukee conditions.............	14	14.2
Minneapolis "	17	8.5
St. Paul "	17	9.8
Duluth "	11	8.9

III. Service Stops.

Congested period.

Period 1.............................	58	16.1
Period 2.............................	31	14.9
Period 3.............................	20	13.1
Average..................	109	15.2

NOTE

The following paper is to be read at the 27th Annual Convention of the American Institute of Electrical Engineers in **Jefferson, N.H., June 28—July 1, 1910**. This paper is to be presented under the auspices of the Railway Committee of the Institute. All those connected with the Institute and desiring to take part in the discussion of this paper may do so by being present at the meeting; or, if this is not possible, by sending in a written contribution.

Written contributions will be read at the meeting, time permitting, for which they are intended, either in full, in abstract, or as a part of a general statement giving a summary of the views of those taking the same position in the matter.

The principal object in getting out the paper in advance of the meeting is to enable and encourage those not in a position to attend the meetings to take part in the discussion by mail.

Contributions to the discussion of this paper should be mailed to **William McClellan, Chairman Railway Committee, 905 West Street Building, New York,** so that they will be received not later than June 23, 1910. Written contributions arriving within 30 days thereafter will be treated as if presented at the meeting.

(PUTNAM

A paper to be presented at the 27th Annual Convention of the American Institute of Electrical Engineers, Jefferson, N. H., June 28–July 1, 1910.

POWER ECONOMY IN ELECTRIC RAILWAY OPERATION—COASTING TESTS ON THE MANHATTAN RAILWAY, NEW YORK

BY H. ST. CLAIR PUTNAM

The power required for the operation of electric railways can be predetermined with great accuracy providing the cars or trains are operated in the manner assumed in the calculation of the speed-time and power curves employed for this purpose. Unfortunately, the cars are seldom operated as they should be, and though allowance for this variation is made engineers have long recognized that a material saving in power could be realized in electric railway operation if the motormen could be induced or trained to operate the trains in a manner approximating the speed-time curve used in the preliminary calculations. It is proposed in this paper to describe some tests made on the Manhattan Elevated Division of the Interborough Rapid Transit Co., New York, in which a clock was used to record the amount of coasting employed in the operation of trains, the object of this device being to obtain from the motormen a better manipulation of the trains with the resulting economy in the use of power.

The clock as used in the tests consists of a clock mechanism manufactured for factory and office use for recording the time of employes. To the balance wheel escapement a braking device has been added, as shown in Fig. 1, which is lifted free from the balance wheel by an electromagnet which is energized only during the coasting of the train. This permits the clock to record the coasting time only. Each motorman is provided with an individual key which he inserts on taking charge of the train and again on leaving. The turning of this key records

the motorman's number or initials and the time as shown by the clock mechanism; the difference in the time between the two records made by the key representing the total time of coasting during his run. The slip record is torn off by the motorman and turned in to the proper official. This is checked up with his running time, and the motorman is rated according to the percentage that the coasting time is of the total time of his run, due allowance being made for variation from the schedule. His individual rating is based upon the average results of a week or month as may be selected.

The electric circuits controlling the clock are interlocked with the master controller and the brake mechanism and arranged so that the coasting clock will start only after the two actions of turning the power on and then off. The connections

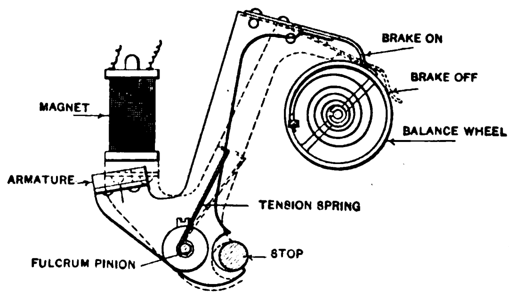


FIG. 1.—Details of clock mechanism

used are shown in Fig. 2. The operation of the clock is stopped as soon as the air brakes are operated and the brake cylinder has started to move to the braking position. If, for any reason, after the brakes are applied, the air is released and additional coasting obtained before the train stops, this additional coasting is lost from the amount of coasting recorded unless power is again applied. This is not an important factor in normal operation as the actual amount of coasting of this character is small.

SPEED TIME CURVE CHARACTERISTICS.

While the principles involved in the use of speed time curve calculations in electric operation are well understood, for the purpose of making clear the economies in power consumption that can be realized from the better operation of trains, which

it is the object of this clock to encourage, the following brief discussion of the various factors entering into electric operation is given.

Acceleration. The rapid acceleration of trains, providing the schedule speed is unchanged, results in an important saving of power for two reasons, first, the maximum speed reached is less with a high acceleration, and consequently the train resistance is somewhat less; second, and of much greater im-

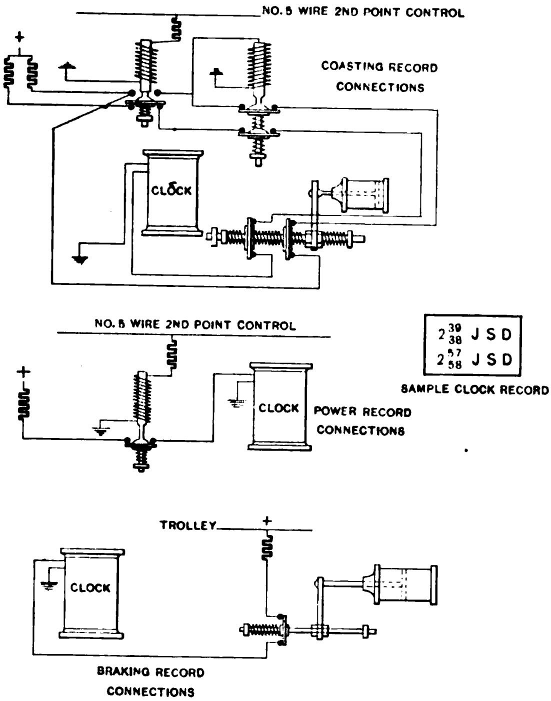


FIG. 2—Clock connections

portance, is the fact that with a high rate of acceleration, the speed at the start of breaking is less than with a lower rate and, consequently, the energy absorbed and lost in braking is less. The energy absorbed in braking is the essence of the whole subject, as in such train operation as that on the Manhattan system, and to a lesser extent in single car operation the increased train resistance resulting from the higher maximum speed due to a slow acceleration is unimportant and may be neglected. The only energy not utilized in useful work is

that absorbed in the rheostats in direct current acceleration, the motor and control losses and the energy absorbed in the brake shoes.

The equipment provided naturally limits the permissible rate of acceleration, but within such limitations, a quick acceleration is one of the most feasible methods of saving power in such service as exists on the Manhattan Railway.

Fig 3 shows the typical average run on the Second Avenue line, using the same rates of acceleration and braking and length of stop as used in the original calculations for the electrification of the Manhattan system but using the train resistance as derived from tests made in 1905. This run as shown is

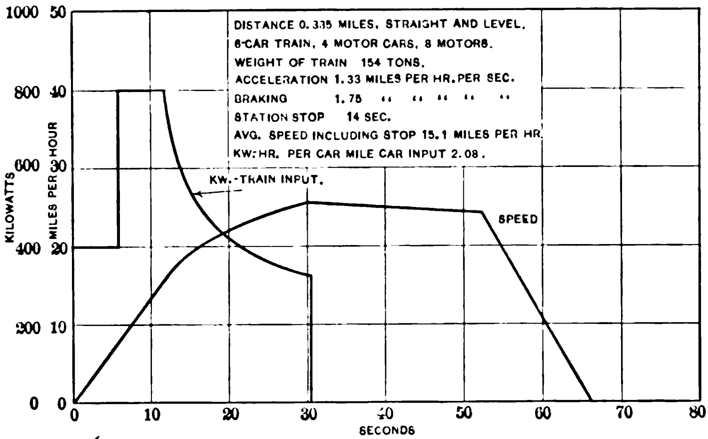


FIG. 3—Typical run

representative of the average run on the Second Avenue line where the coasting clock tests have been made, and is also representative of the average run of the entire Manhattan system. The distance between stations on the portion of the Second Avenue line tested, between Canal Street and 127th Street, is 1768 ft. as compared with 1763 ft. for the entire Manhattan system. In this typical curve the acceleration used is 1.33 miles per hour per sec. and the schedule speed is based upon the printed schedule of the road.

Fig. 4 shows the original speed-time curve used in the electrification of the Manhattan Division, and it will be noted is in close agreement with the curve shown in Fig. 3.

In Fig. 5 is shown the precentage increase in coasting time

resulting from the increase in the rate of acceleration from 0.9 miles per hr. per sec. to two miles per hr. per sec., and the resulting decrease in power consumption, based upon an average run on the Second Avenue line. In the tests on the entire Manhattan system conducted on March 22, 1910, the acceleration of different motormen was found to vary from 0.9 miles per hr. per sec. to 1.47 miles per hr. per sec. Providing other factors of train operation remain the same (that is, the braking, running time and time of stop) the increase in the rate of acceleration from 0.9 to 1.47 miles per hr. per sec. will result in an increase in the

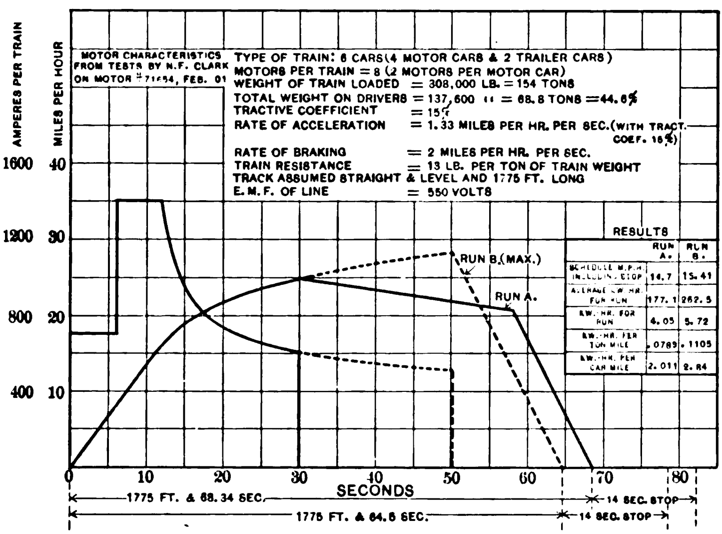


FIG. 4—Speed and power curves for train with eight motors
Gear ratio 71:18 = 3.94—Wheel diam. = 33 in.

percentage of coasting time from 0 to 40.5 per cent of the total time, and a saving of 36 per cent in energy consumption. A motorman on the Manhattan system on full runs will average about 600 car miles per day, and the power used at the car with 0.9 acceleration will approximate 2.82 kw. hr. per car mile. As between these two motormen, therefore, providing the scheduled speed is maintained, the motorman who accelerated his train at an average rate of 0.9 miles per hr. per sec. will waste during the day 610 kw-hr. at the car. With 80 per cent efficiency to the power house, this becomes 762

kw-hr. This power of course must be supplied fron the power house where additional apparatus must be installed to meet the demand. In practice the full saving of power resulting from better acceleration is not realized, owing usually to the better running time made by the good operator. This results frequently in his having to wait for the train ahead and by so doing, a large part of the saving in power which should follow his good operation is lost. The use of this clock should result, however, in a material increase in coasting time under such circumstances, with a resulting saving in power. The men will learn to gauge their trains, and instead of stopping for the man ahead, will utilize the surplus time in coasting. In order that

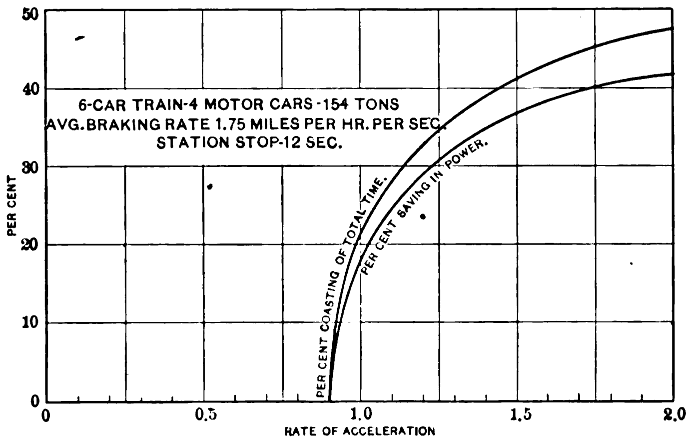


FIG. 5—Influence of acceleration

schedules shall be maintained, however, some sort of penalty must be imposed to prevent the motorman from over-doing the coasting at the expense of the running time.

Series Running. In Fig 6, the effect of series running upon the percentage of coasting obtained and the resulting power consumption is shown. It will be noticed that an increase in the percentage of coasting obtained by reducing the amount of series running does not effect a corresponding saving in power. This is due to the fact that while the total time during which power is applied is increased and the time of coasting reduced by holding the controller in the full series position, say for four or five seconds, the actual power used remains practically the same because the additional power required on account of

the longer time of power application is offset in large measure, if not entirely, by the saving in rheostat losses owing to the reduced time that the rheostat is in circuit in passing to full multi-

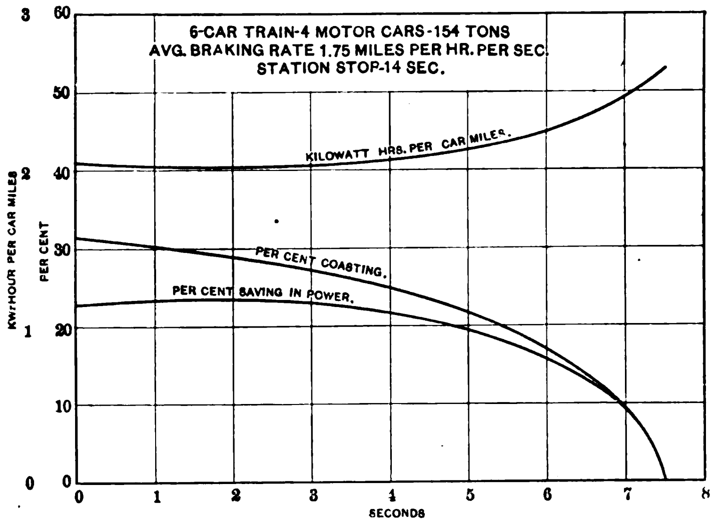


FIG. 6—Influence of series running

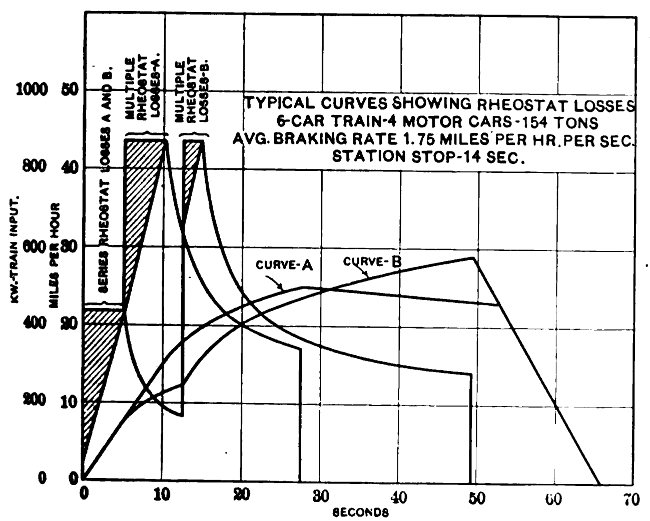


FIG. 7—Influence of series running

ple. This is shown in Fig. 7, which has been used in calculating the results plotted in Fig. 6. A limited amount of series running, therefore, is not objectionable, and under certain

conditions it is better to run in series for a short time than to pass to the multiple position, especially where power is cut off almost immediately after the multiple position is reached as under certain conditions in approaching a station. The decrease in coasting time resulting from a moderate amount of series running does not therefore necessarily represent an increase in power consumption, unless the series running has been excessive. In this respect the coasting clock will give misleading results; but as under normal conditions there is little occasion for running in series, excepting around curves, the error thus introduced into the record is not important.

Braking. A high rate of braking results in a reduction in

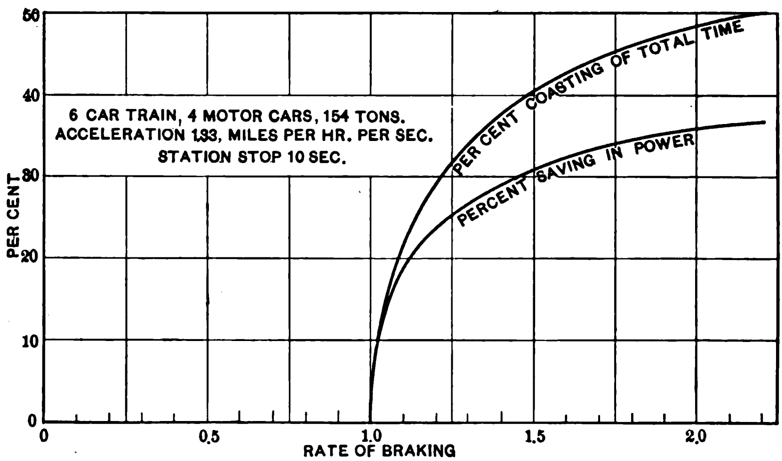


FIG. 8—Influence of braking

power consumption for reasons similar to those existing as to the rate of acceleration. It permits the power to be cut off at an earlier point, a longer time of coasting introduced, power otherwise wasted in the brakes to be recovered and the train brought to a quick stop. Perfection in braking is much more difficult of attainment than acceleration, as the train must be stopped at the station within a space limited to a few feet. The motorman, therefore, in approaching a station must judge his distance, speed, grades, if any, as well as the weight of his train, and over-running the station causes serious delay. Many motormen therefore, operate on the side of safety and feel their way into stations, with a resulting material increase in the power used if schedules are maintained.

In Fig. 8, is shown the percentage of power saved on account of the increased percentage of coasting introduced by increasing the rate of braking from one mile per hr. per sec. to 2.25 miles per hr. per sec. These limits are frequently found in the operation of Manhattan trains. Two miles per hour per second is entirely practical as has been determined by carefully conducted tests. An increase in the rate of braking between the limits of one mile per hr. per second and two miles per hr. per sec. results in increasing the coasting to 48.5 per cent. of the total time with a saving in power of 35.5 per cent.

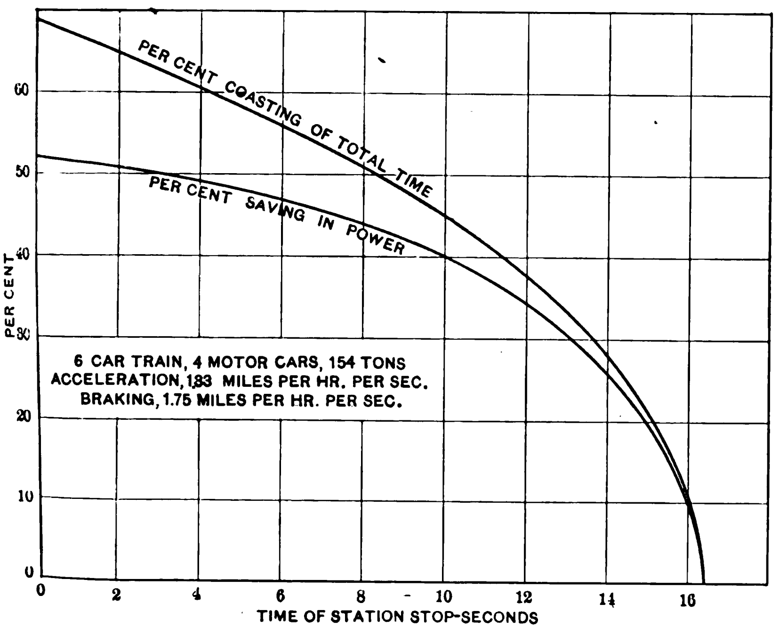
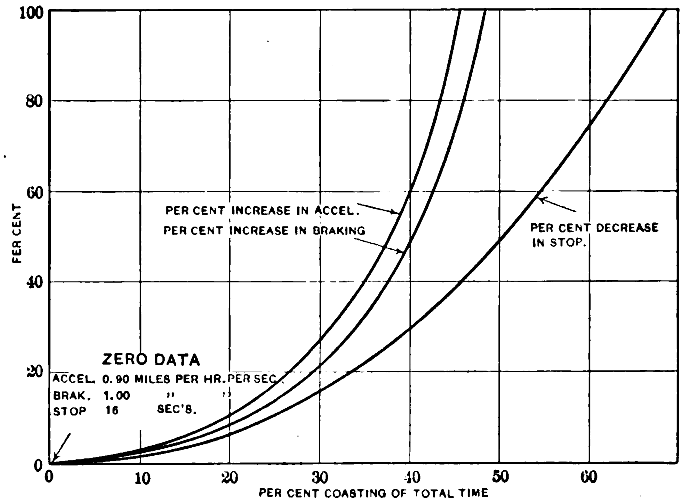


FIG. 9—Influence of station stop

In the tests made over the Manhattan system on March 22nd, the trains were not equipped for getting the braking rate. The average time required by the motorman in bringing the train to a stop varied from 10.2 sec. to 20.2 sec. This would indicate approximate braking rates of 1.15 and 1.90 miles per hour per sec. The higher rate would increase the coasting time from 26 per cent for the lower rate, to 47.5 per cent, and result in the saving of approximately 280 kw-hr. per day by the better operator.

Station Stops. In Fig. 9 is shown the influence of the station

stop. On the Second Avenue line, the average run is 0.335 miles and the maximum possible stop with the maintenance of the schedule, and with no coasting, is 16.2 sec., assuming an average run as typical, which is substantially correct for the purposes of the present discussion. A reduction in the



Percentage change in operating conditions and resulting percentage of coasting

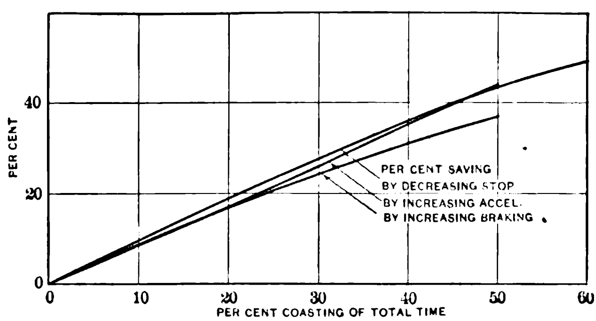


FIG. 10—Percentage saving in power corresponding to percentage of coasting

time of stop to 10 sec. results in an increase in coasting time to 45 per cent of the total time and a reduction of 40 per cent in the power used.

Coasting. The amount of coasting which a motorman can obtain and still maintain his schedule, is obviously the result

of the factors of operation above discussed. The ideal amount of coasting will result from the observance of all these factors. The theoretical coasting as shown on the typical curve is 27.5 per cent of the total time including stops. It has been shown in the above dicsussion that it is possible to obtain this amount of coasting and even to exceed it by changes in operation which are entirely within the range of practicability.

In Fig. 10, is shown the percentage of change made in these operating factors and the resulting percentage of coasting obtained and the corresponding percentage of power saved. It will be noted that it makes but little difference which factor is altered. The percentage of power saved is substantially

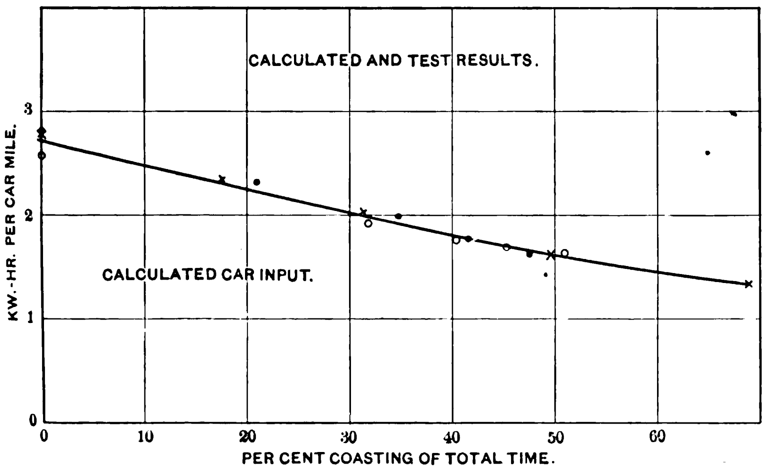


Fig. 11—Power required per car-mile

the same however the increased coasting is obtained. This of course is to be expected. It is well to point out the very large saving in power consumption which results in reducing the stop from say 15 sec. to 10 sec. assuming that the schedule speed remains the same. This results in the saving of 25 per cent in power through the increased coasting thus made possible.

Power Consumption. In Fig. 11, the calculated power required at the car, per car mile, is plotted under different conditions as to acceleration, braking and station stops as above discussed, these factors being plotted in terms of the resulting percentage of coasting obtained. This curve illustrates graphically the very material saving in power effected by any change

in the methods of operation which results in an increase in the coasting time.

Second Avenue Test Results.

The results of the tests of the coasting clock which have been conducted on the Second Avenue line are plotted in Fig. 12. All trains on the Second Avenue line were equipped

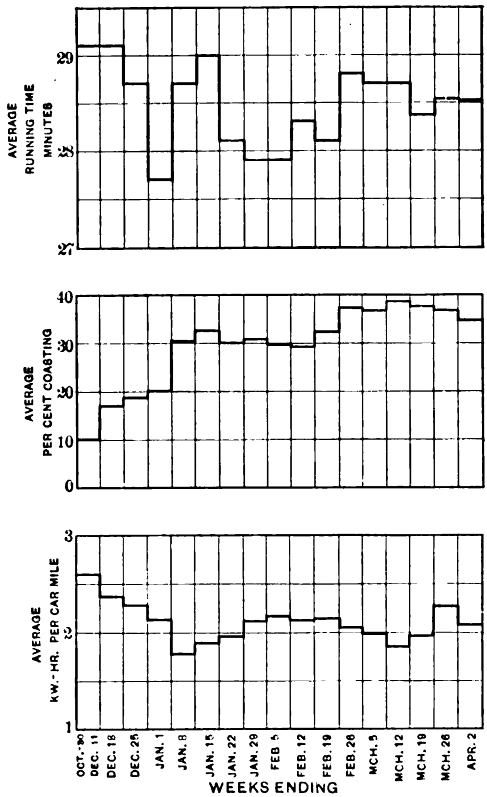


Fig. 12—Coasting clock tests on Second Ave line 127th St., to Canal St.—Oct. 30 to Dec. 11 before clock installation—Dec. 18 to Apr. 2 after clock installation

with coasting clocks, and the power supplied to the section between 127th Street and Canal Street was metered by direct-current integrating wattmeters on the substation feeders. Corrections have been made for heaters and light, and the wattmeter readings corrected in accordance with frequent calibrations.

On account of the corrections that have to be made for heaters light, control and auxiliaries, the results obtained are necessarily approximate. Under these circumstances, therefore, the records are remarkably consistent and show graphically the material improvement in coasting which has resulted from the use of the coasting clock, and also the reduction in the power required for the operation of the cars.

In Fig. 13, the power required per car-mile as shown by these tests is plotted in terms of the percentage of coasting.

In Fig. 14, the average curve obtained from the Second Avenue tests and the average curve as obtained from our calculations, both expressed in terms of kw-hr. per car-mile, and the percentage of coasting obtained, are plotted on the same sheet. The agreement of these curves is remarkably close, the curves

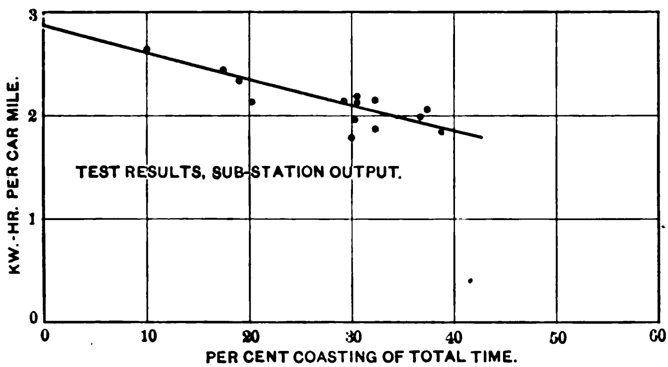


FIG. 13—Power required per car-mile

expressing the percentage of power saved from the increased coasting practically coincide. Of course this is as it should be if the calculations and tests have been correct. Quantitatively, the power per car mile obtained from the tests is about seven per cent higher than the calculations. The test results are measured at the substation while the calculations are at the car. The difference would represent the third rail losses, but it is believed that they are somewhat greater than this would indicate. The important feature contained in this curve is that on the Second Avenue line the increase in the time of coasting from 10 per cent as it was prior to the installation of the clocks to 38 per cent following such installation, resulted in a saving of 25 per cent in the power required for traction. This result is an agreement with what should be expected from the theoretical calculations.

MANHATTAN TESTS—MARCH 22, 1910.

On Second, Third, Sixth and Ninth Avenue Lines.

In order to compare the operating conditions existing on the Second Avenue line with the conditions on the other lines

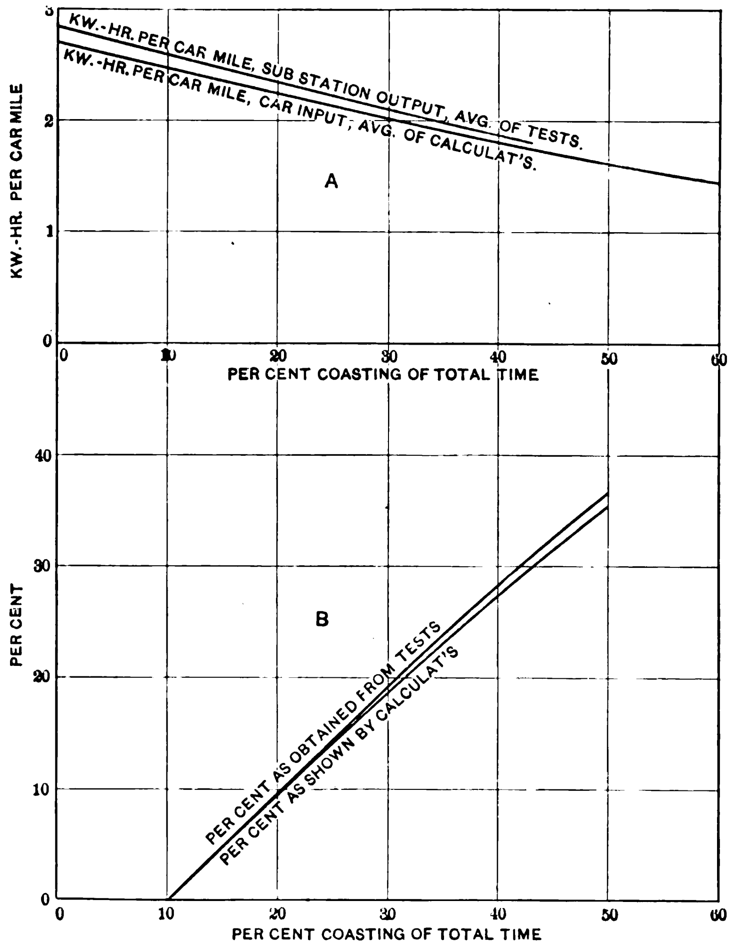


FIG. 14

A-Kilowatt-hours per car-mile

B-Percentage of power saved resulting from coasting

of the Manhattan system, on March 22nd a test train was run in actual sevice over all divisions of the Manhattan system. A seven-car train composed of four motor and three trail cars was used. Each trail car was equipped with one of the record-

RECORDING CLOCK TESTS—MARCH 22, 1910. MANHATTAN DIVISION. INTERBOROUGH RAPID TRANSIT COMPANY

	Power applied min.	Coast-ing min.	Braking min.	Stops min.	Total time by watch minutes
Second Ave. 129 *to S. Ferry*					
Test No. 1—Stop watches	11.7	18.8	5.3	7.0	42.3
8:01 a.m. S.—Recording clocks	11.9	19.6	6.3		
Test No. 2—Stop watches	11.1	19.8	4.4	3.7	39.1
8:45 a.m. N.—Recording clocks (To 127th St. only)	10.5	20.9	4.9	—	—
Test No. 5—Stop watches	12.0	15.8	5.0	4.8	37.5
1:23 p.m. S.—Recording clocks	11.0	17.0	5.7	—	—
Third Ave. Bronx Pk. City Hall					
Test No. 3—Stop watches	27.1	7.5	11.3	10.4	56.7
9:45 a.m. S.—Recording clocks	26.0	6.3	12.5	—	—
Test No. 4—Stop watches	21.1	15.4	9.8	8.9	55.1
10:53 a.m. N.—Recording clocks	19.8	17.8	10.0	—	—
Sixth Ave. 155th St. to S. Ferry					
Test No. 6—Stop watches	19.2	10.7	8.6	8.1	46.8
2:6 p. m. N.—Recording clocks (Start Battery Place)	18.0	11.0	9.0	—	—
Test No. 9—Stop watches	19.9	10.3	10.4	6.6	47.9
4:23 p.m. S.—Recording clocks	18.5	11.5	12.5	—	—
Ninth Ave. 155th St. to S. Ferry					
Test No. 7—Stop watches	19.9	8.1	8.6	6.0	42.9
2:55 p.m. S.—Recording clocks	18.2	8.2	8.7	—	—
Test No. 8—Stop watches	19.4	9.1	9.3	4.5	43.2
3:39 p.m. N.—Recording clocks	17.8	10.0	9.3	—	—

AVERAGE OPERATING CONDITIONS. RECORDING CLOCK TESTS—MARCH 22, 1910. MANHATTAN DIVISION

	Average Length of run feet	Average acceler-ation seconds	Average Power applied seconds	Average coast-ing seconds	Average brak-ing seconds	Average stop seconds		Average total time seconds
						Sta-tion	Sig-nal	
Second Ave.								
Test No. 1-S	1723	11.4	26.0	41.7	11.9	13.2	2.4	95.2
Test No. 2-N	1752	11.5	25.7	45.6	10.2	8.8	—	90.3
Test No. 5-S	1723	10.3	26.7	35.0	11.2	9.9	1.3	84.1
Third Ave.								
Test No. 3-S	1767	14.6	42.7	11.8	17.9	16.8	—	89.2
Test No. 4-N	1767	12.8	33.2	24.2	15.6	13.2	1.3	87.5
Sixth Ave.								
Test No. 6-N	1841	14.5	38.5	21.4	17.1	14.3	2.5	93.8
Test No. 9-S	1833	11.4	38.4	19.9	20.2	11.2	2.0	91.7
Ninth Ave.								
Test No. 7-S	1833	17.2	41.1	16.7	17.8	11.3	1.6	88.5
Test No. 8-N	1833	19.1	40.2	18.7	19.3	9.3	0.6	88.1

ing clocks. These clocks were connected as shown in Fig. 2. One clock was used to record the coasting time, the second the time of power application, and the third the time of braking. Stop watch records were also made of the time of series running and total power application, time of coasting, time of braking and time of station and signal stops.

The result of these tests are tabulated on the preceding page.

Second Avenue Tests

The results of the tests over the Second Avenue line reduced to an average run are plotted in Fig. 15 in what we have called "Running Charts" for each of the three tests on this division. These curves approximate speed-time curves in form, but naturally as the different factors which enter into the characteristics of the curve are averages, the resulting curve does not pretend to give the correct area and distance. The curve is but a picture of the average operating conditions of the run.

It will be noted that motorman *S* in test No. 2 obtained 50.5 per cent coasting, the largest amount recorded during the day. Of the three tests on Second Avenue, motorman *O* in test No. 5, obtained the smallest amount of coasting, 41.4 per cent and carried power for the longest time, 31.6 per cent, yet he was the best operator of the two. If he had used the same time in making the run as motorman *S* in test No. 2, it would have been possible for him to obtain as high as 58.5 per cent coasting as shown by the broken line on test No. 5, and he could have cut his power application down to 22.2 per cent with a saving of 8 per cent in power as compared with motorman *S* in test No. 2. The good results in test No. 5 were obtained with an acceleration of 1.47 and braking of 1.85 (approximate) as compared with an acceleration of 1.35 and braking of 1.75 (approximate) in test No. 2. The rate of braking indicated on these curves is approximate only, as the average braking includes the signal braking between stations and at curves in addition to the braking at station stops. The slope of the braking curve, however, indicates quite accurately the relative rate of braking used by the motorman.

The motormen who operated the trains in the tests on the Second Avenue line were selected men and the runs were made to illustrate what could be accomplished after a thorough training of several months. The average coasting obtained in the three runs is 45.2 per cent. This indicates a saving in

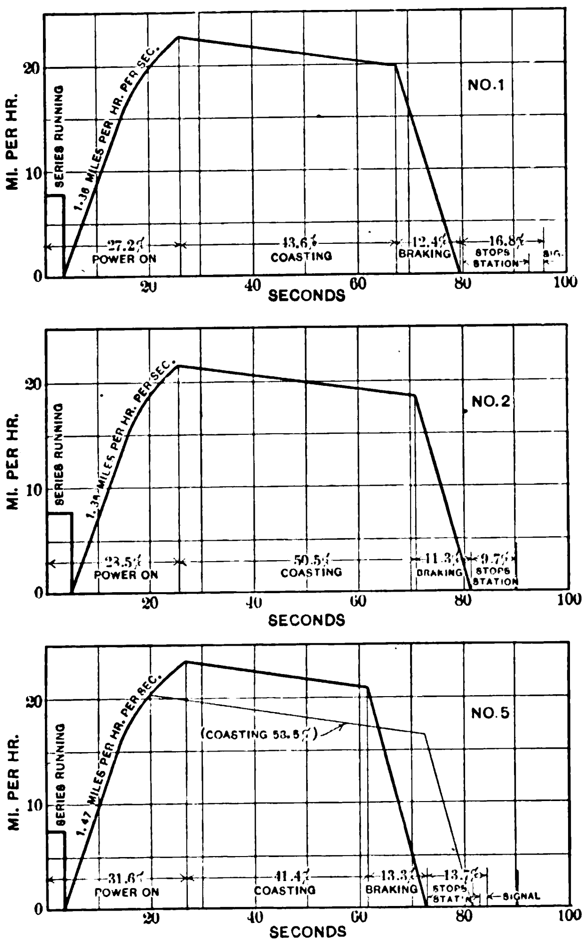
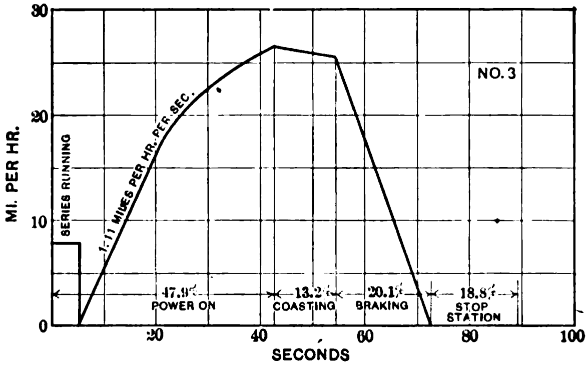


Fig. 15—No.1. Typical running chart, 129th St. to South Ferry—
8:01:20 a.m. to 8:40:43 a.m.—Motorman S—
Schedule time 35 min—27 runs—Average run 1723 ft.—
Average speed 12:3 miles per-hr.
No. 2. Typical-running-chart, South Ferry to 127th St.—
8:45:20 a.m. to 9:24:23 a.m.—Motorman S—
Schedule time 34:5 min. 26 runs—Average run 1,752-ft.—
Average speed 13:2 miles per hr.
No. 5. Typical-running-chart 129th St. to South Ferry—
1:23:15 p.m. to 2:0:45 p.m.—Motorman 0—
Schedule time 35 min.—27 runs—Average run 1,723 ft.—
Average speed 13.9 miles-per hr.

power consumption amounting to 34 per cent as compared with the conditions existing on this line prior to the installation of the clocks. This, of course, is in excess of the average saving of all the men as these men were specially selected.



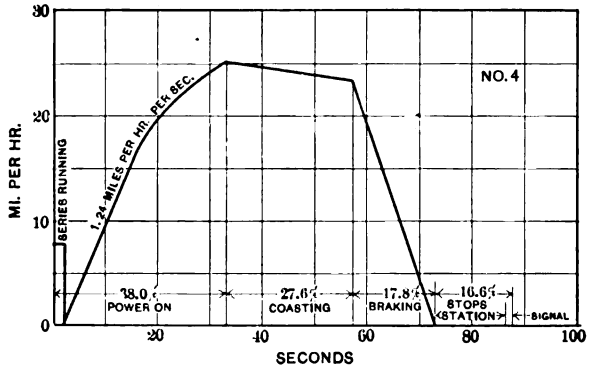


FIG. 16—No. 3. Typical running chart, Bronx Park to City Hall—
9:54:04 a.m. to 10:50:46 a.m.—Motorman C—
Schedule time 51 min.—38 runs —Average run 1,767 ft.—
Average speed 13:5 miles per hr.
No. 4. Typical running chart, City Hall to Bronx Park—
10:53:45 a.m. to 11:48:50 a.m.—Motorman G—
Schedule-time 51 min.—38 runs—Average run 1,767 ft.—
Average speed 13.8 miles per hr.

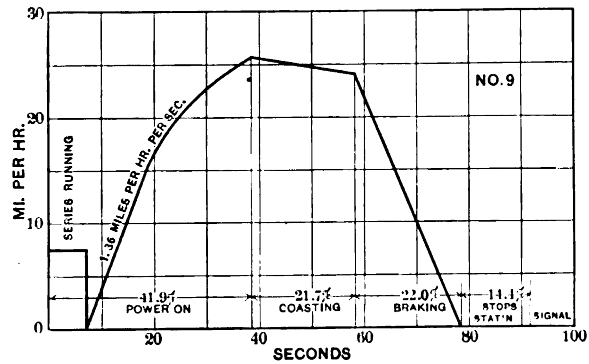
These tests also bring out strongly that any system of rewards or ranking of the men based upon coasting time should include a penalty for overrunning the scheduled time.

The tests on the Second Avenue line, as observed, show

an average of 45.2 per cent coasting which corresponds to 1.70 kw-hr. per car-mile at the car.

Third Avenue Tests

Fig. 16, shows the average Running Charts obtained from



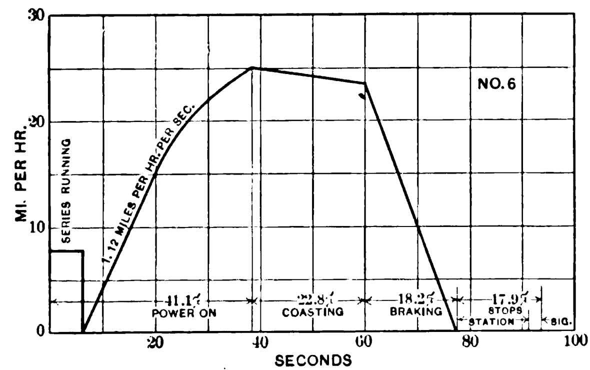


Fig. 17—No. 9. Typical runing chart. 155th St. to South Ferry—
4:25:07 p.m. to 5:13:00 p.m.—Motorman C—
Schedule-time 43 min.—31 runs—Average run 1,833 ft.—
Average speed 13.7 miles per hr.
No. 6. Typical running chart, Battery Pl. to 155th St.—
2:06:37 p.m. to 2:53:25 p.m.—Motorman W—
Schedule time 4:15 min.—30 runs—Average run 1,841 ft.—
Average speed 13.4 miles per hr.

the tests on the Third Avenue line. In the Third Avenue tests, the run south was made with the motorman whose turn it happened to be. This run shows 13.2 per cent coasting. The run north was made with an experienced man and shows 27.6

per cent coasting. The difference is due mostly to the difference in the rate of acceleration, but partly to the braking rate and partly to an excessive amount of series running in test No. 3.

These two runs show an average of 20.4 per cent braking which indicates 2.22 kw-hr. per car-mile at the car. These men, therefore, used 30.6 per cent more power than was used by the men on the Second Avenue test.

Sixth Avenue Tests

Fig. 17 gives the Running Charts of the two tests made on the Sixth Avenue line. The motormen were taken as they come, and it will be noted that their handling of the train is in fairly close agreement.

On account of the number of turns on this line, the amount of necessary series running is considerably in excess of that obtaining on the other lines. The average coasting obtained was 22.3 per cent. This corresponds to a power consumption of 2.17 kw-hr. per car-mile. As compared with the average obtained in the Second Avenue tests, this represents an excess consumption of power of 27.7 per cent.

Ninth Avenue Tests

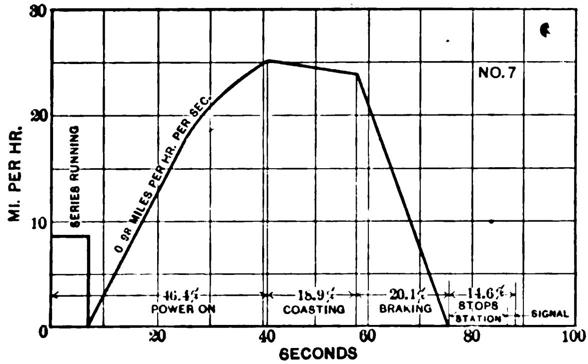
Fig. 18 gives the Running Charts of the tests made on the Ninth Avenue line. The motormen were taken as they came, and it will be noted that the two men operated their trains very much alike. In both cases the acceleration was poor and the braking somewhat below the standard. Both used a large amount of series running.

The Ninth Avenue line is an ideal one on which to obtain a large amount of coasting on account of the longer runs, easy schedule and long grades, yet the coasting obtained by these two men was but 18.9 per cent and 21.2 per cent respectively. and averages 20.1 per cent. As compared to the average obtained in the Second Avenue tests, this represents an excess consumption of power of 31.8 per cent.

Clock Records on Third, Sixth and Ninth Avenue Lines

In the tests conducted on March 22nd, the motormen were conscious of being under observation by the test crew as well as by their own road officials, and under such circumstances they naturally tried to do their best. The results obtained therefore, cannot be regarded as representative of actual con-

ditions, but can be taken as fairly representing the best that these men could do, and therefore, as illustrating the knowledge of the motormen in general. The tests were too few in number, however, and the conditions under which they were made were such that they are not regarded as representative.



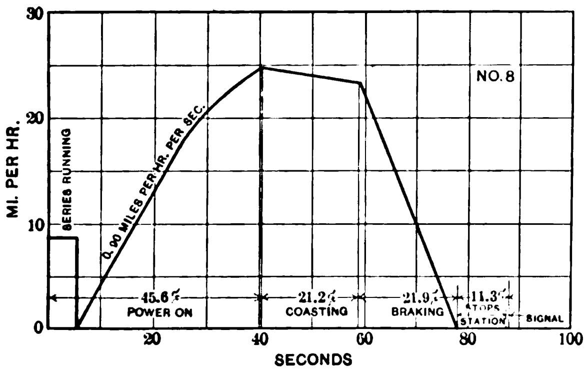


FIG. 18—No. 7. Typical running chart, 155th St. to South Ferry—
2:55:07 p.m. to 3:38:00 p.m.—Motorman M—
Schedule time 40 min.—29 runs—Average run 1,833 ft.—
Average speed 14.1 miles per hr.
No. 8. Typical running chart, South Ferry to 155th St.—
3:39:20 p.m. to 4:22:35 p.m.—Motorman C—
Schedule time 40 min.—29 runs —Average run 1,833 ft.—
Average speed 14.2 miles per hr.

In order to determine the fair average conditions as to coasting existing on all divisions of the system, tests were made on the Second and Third Avenue lines last fall and two trains equipped with clocks were put in regular service this spring on the Sixth and Ninth Avenue lines.

The average of these results should be fairly representative of the coasting conditions at present, as well as prior to the installation of the coasting clock on the Second Avenue line. The men soon become aware of the trains equipped with clocks, however, and consequently are more careful in the operation than usual. It is probable, therefore, that the coasting data obtained from these tests are above rather than under the average conditions.

The results obtained on the Second Avenue line will be found plotted in Fig. 12, and show that prior to the installation of the clock, the coasting averaged 10 per cent of the running time. These tests were started in October and continued daily to December 11th.

Tests were made on the Third Avenue line last summer and the results agree very closely with those obtained at a later date on the Second Avenue line. The data collected on a test of ten days duration is given below:

THIRD AVENUE—SCHEDULE TIME—51 MINUTES

	Runs	Average running time minutes	Average coasting time minutes	Per cent coasting
July 16	7	52.9	6.3	11.8
July 22	6	51.3	8.4	16.4
July 27	3	52.2	3.7	7.1
July 28	7	52.9	3.3	6.2
July 29	7	52.3	3.2	6.1
July 30	7	52.8	5.1	9.7
July 31	4	53.6	6.2	11.5
Aug. 2	5	52.7	6.3	11.9
Aug. 3	7	52.6	5.9	11.2
Aug. 4	7	53.3	5.9	11.1
Average	60	52.7	5.4	10.2

Below is given the coasting tests recently made on the Sixth Avenue line. It will be noted that the amount of coasting agrees very closely to that existing on the Third and Second Avenue lines prior to the installation of the coasting clock.

SIXTH AVENUE—SCHEDULE TIME—43 MINUTES

	Runs	Average running time minutes	Average coasting time minutes	Per cent coasting
March 28	16	45.9	6.1	13.2
March 29	10	46.8	5.7	12.2
March 30	10	46.7	5.2	11.1
March 31	8	45.9	5.3	11.5
April 1	2	44.0	3.6	8.2
April 2	10	46.2	5.2	11.3
Average	56	46.2	5.5	11.9

The Ninth Avenue line as already mentioned, furnishes an ideal one upon which to obtain a large amount of coasting, on account of its undulating grades, longer distance between stations, and easy schedule. In addition to this, the average train on this line is made up of four motor cars and two trailers instead of four motor cars and three trailers, as on the other lines. The effect of these factors is seen in the results obtained from the coasting tests which are given below.

NINTH AVENUE—SCHEDULE TIME—40 MINUTES

	Runs	Average running time minutes	Average coasting time minutes	Per cent coasting
March 28	5	37.7	4.9	12.9
March 29	12	38.0	6.9	18.0
March 30	13	36.5	7.8	21.4
March 31	12	38.0	7.6	19.9
April 1	15	37.3	7.0	18.7
April 2	12	37.0	7.9	21.3
April 3	8	41.7	8.3	19.9
Average	77	37.8	7.4	19.1

SUMMARY—COASTING DATA

	Car miles per day	Per cent coasting
Second Avenue	28,863	10.0
Third "	79,403	10.2
Sixth "	46,571	11.9
Ninth "	33,826	19.1
Average	188,663 (total)	12.2

From the above tests it is probable that the average coasting obtained on the Manhattan system approximates 12 per cent of the running time. On account of the fact that the motormen are very alert to discover that they are under observation, it is probable that the actual amount of coasting is below, rather than above, this amount.

Result of Equipment with Coasting Clocks

In the table below is given the average coasting obtained during five weeks on the Second Avenue line, where the coasting clock has been in service for slightly over three

months. The average run on this part of the Second Avenue line, as already pointed out, closely approximates the average run for the entire Manhattan system.

SECOND AVENUE LINE—COASTING DATA. COASTING CLOCK INSTALLED FOR THREE (3) MONTHS

	Average running time	Average coasting time	Per cent coasting
Week ending March 5	28.7	10.5	36.8
" " " 12	28.7	11.1	38.8
" " " 19	28.5	10.8	37.7
" " " 26	28.5	10.6	37.0
" " April 2	28.4	10.1	35.4
Average	28.6	10.6	37.1

Value of Power Saved Through Coasting

The result of these calculations and tests shows that an increase in the percentage of coasting from 12 per cent to 37.5 per cent as shown above, will effect a saving of 24 per cent in the power required for traction.

Coasting vs. Power Measurements

The various factors that enter into the operation of the train have been analyzed with a view to determine which is the preferable element to measure. The choice practically narrows down to the measurement of either the power input by wattmeter or time of application by means of a clock arrangement, or the measurement of the time of coasting. It is believed that it has been made clear that whatever good results are obtained from the better operation of the train by the motormen can only result in the saving in power through the increase in the coasting time. Coasting is the recovery of power already used, and hence is the key to the problem. The coasting clock, therefore, gives a direct measure of the power *recovered* by the motormen and as this recovery can also only be made by cutting off the power application sooner, it is believed that it is the most effective element in train operation to measure. At the same time it concentrates the motorman's attention on that element of operation which is the direct reason for the saving in power which results from changes in the methods employed as to the other factors of operation.

This subject has been discussed at some length, as it brings up some interesting features of electric train operation. Preliminary schedules for electric operation in service similar to that on the Manhattan system, usually included from 25 to 30 per cent coasting, partly for the reasons of power economy and partly to provide a factor of safety, as it has been realized that motormen do not operate their trains in compliance with the calculated speed-time curve. It is believed that the use of the device here described will not only insure the better operation of trains but will result in a material saving in the power used.

The writer is indebted to Mr. L. B. Stillwell and officials of the Interborough Rapid Transit Company for the use of material embodied in this paper.

NOTE

The following paper is to be read at the 27th Annual Convention of the American Institute of Electrical Engineers in **Jefferson, N. H., June 28 – July 1, 1910.** This paper is to be presented under the auspices of the Railway Committee of the Institute. All those connected with the Institute and desiring to take part in the discussion of this paper may do so by being present at the meeting; or, if this is not possible, by sending in a written contribution.

Written contributions will be read at the meeting, time permitting, for which they are intended, either in full, in abstract, or as a part of a general statement giving a summary of the views of those taking the same position in the matter.

The principal object in getting out the paper in advance of the meeting is to enable and encourage those not in a position to attend the meetings to take part in the discussion by mail.

Contributions to the discussion of this paper should be mailed to **William McClellan, Chairman Railway Committee, 905 West Street Building, New York,** so that they will be received not later than June 23, 1910. Written contributions arriving within 30 days thereafter will be treated as if presented at the meeting.

(HOPKINS)

A paper to be presented at the 27th Annual Convention of the American Institute of Electrical Engineers, Jefferson, N.H., June 28-July 1, 1910

ECONOMY OF CAR OPERATION

BY CYRIL J. HOPKINS

Introduction. The object of this paper is to show quantitatively the value of coasting in terms of change in average speed, and running time, and also to make special references to the value of antifriction bearings.

No truer statement was ever made than that recently by Mr. Thomas W. Hinkle that[1] "Electric railway companies are spending large sums of money in building modern power plants and equipping them with efficient machinery, but, after the power goes out to the line, no record is kept of it and the motorman uses it either wastefully or economically, depending upon his intelligence and care."

Again we have an editorial statement with which every one will agree,[2] "Viewed in a broad way, the cost of energy required in railway operation is a minor factor in the final result. The major question is the acquisition of traffic and it is usually economy to subordinate every other factor to it."

If the saving in energy were the only advantage derived from coasting, it might in some cases be admissible to overlook its value in consideration of the last broad assertion. That this is not so, however, is evident from a single incident —that of the Philadelphia Subway—in which it was found that as a result of the installation of coasting signs, not only was the energy consumption reduced by about one-third, but also the brake maintenance by almost the same amount. Furthermore, riding on a train is most pleasant during coasting and most unpleasant during the braking period. If we increase the former and decrease the latter, it is making the train service more comfortable

1. *Electric Railway Journal*, Aug. 28, 1909, p. 325.
2. *Electric Railway Journal*, Sept. 18, 1909, p. 422.

for the passengers and thus aiding in an effective and economical way the acquisition of traffic. Not only do we thus aid in the acquisition of traffic, but the savings in energy and maintenance can be shown in definite figures. In this connection it must not be overlooked that the cost of brake upkeep is usually the largest item among the maintenance charges.

As all railway systems are similar in a general way only, and, in almost all cases, possess a number of individualities, in order to make my statements more comprehensive, all subsequent calculations and tests have been referred to a typical 600-volt interurban railway system—the Atlantic City and Shore R. R.

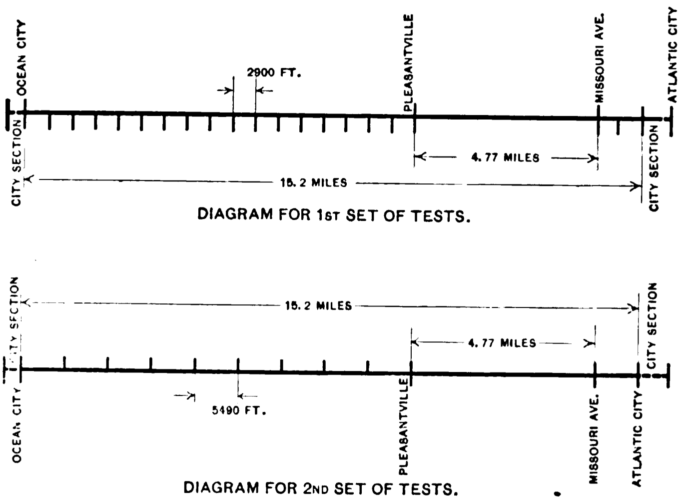


FIG. 1—Distances between stops

Every one is familiar with the large amount of energy that is used in providing the desired acceleration of cars. It is a very simple matter to calculate this, and it is therefore not necessary to dwell upon it, but the proportion of this energy to the total used in propelling the car is not quite so evident, unless detailed computations are carried out.

OUTLINE OF TESTS—ATLANTIC CITY AND SHORE R. R.

The interurban section of this road is 15.2 miles long, of which some 13½ miles are double track. Two series of tests were carried out, one making all, and the other only compulsory stops. The diagram, Fig. 1, gives the average distance between stops in each case.

The tests were carried out with two cars, exactly similar, except that one had ball bearings on the main journals, Fig. 2, and the other had ordinary brass bearings. Ten complete trips were made first with the plain bearing car. Conditions of running were then imitated as nearly as possible with the ball bearing car. The cars used in these tests weigh 36 tons empty and carry 8 tons of passengers when crowded. It will be noted that in each of the diagrams in Fig. 1, one long stretch of about 4¾ miles between stops exists, while the other stretches of track between stops are nearly equal and can be averaged as shown in the diagram, to 2,900 ft. in one case, and 5,490 ft. in the other.

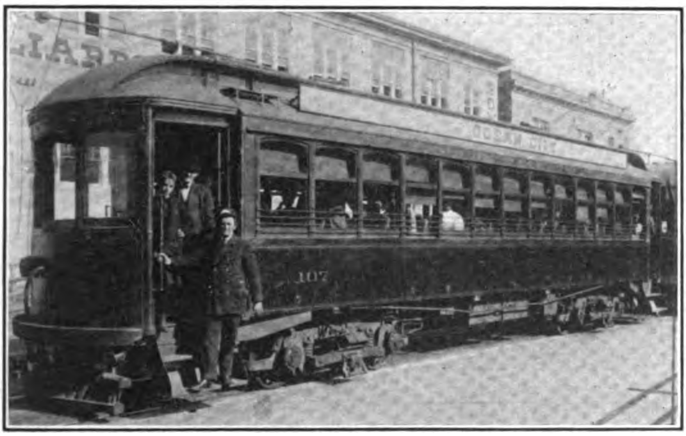


FIG. 2—Car with ball-bearing journals

Instruments. The instruments used in these tests were a 300-ampere integrating railway type wattmeter, a 100-mile speedometer and a voltmeter. The wattmeter, the most important instrument, was new and calibrated immediately after the tests. The following is a recalibration for this meter by the manufacturer after completion of tests.

Amperes	Meter reading 600 volts
400	2.3 per cent fast
300	2.5 " " "
200	2.0 " " "
100	4.3 " " slow
50	17.6 " " "

As the accuracy of a wattmeter is very rightly questioned by all who are interested in results attained thereby, it is worth while to note that from zero to average speed at about 26 miles per hour the current is between 400 amperes and 200 amperes and drops down to 100 amperes at a speed of about 40 miles per hour, hence the error in the wattmeter reading is within $\pm$ 2 per cent, which is satisfactory. Any other method of energy measurement would hardly give more accurate results.

The voltmeter was used to check up line voltage conditions, and to see that they were comparable for both types of car; consequently a calibration of this voltmeter against the substation voltmeter was sufficient.

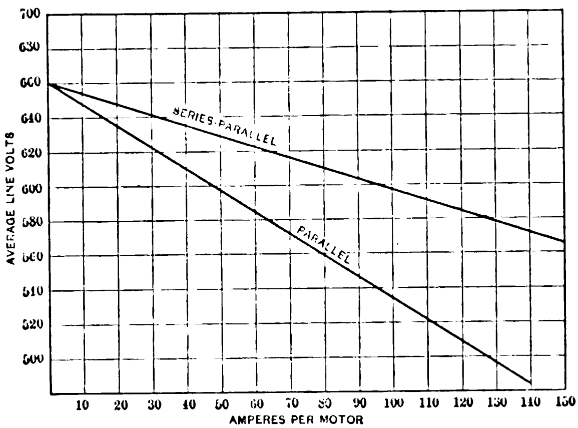


FIG. 3—Voltage characteristics

The speedometer was also used in a general way to check maximum speeds and note the rate of braking; its frequent calibration with a stop watch was of course very simple.

Characteristic Curves. In presenting characteristic curves, as is customary in manufacturers' bulletins, a constant line voltage is assumed; for instance, 600 volts for a system which has a maximum line voltage of 660. From a study of the voltmeter readings for this particular system the voltage characteristics given in Fig 3 have been obtained. The principal differences existing between these conditions and an assumed constant voltage are first that the off-control point is reached sooner, and second, that the relation between the draw-bar pull to overcome train resistance and that producing acceleration has a greater ratio. But on the other hand, with the varying

instead of constant voltage, the car attains a higher maximum speed, accelerating for a greater time at a lower average rate.

From these voltage curves the characteristic curves for the motors have been prepared for the measured wheel diameter of $31\frac{1}{2}$ in., originally 33 in. They have been plotted with draw-bar pull and amperes as ordinates against speeds in miles per hour as abscissæ. In this form they are more convenient for use in calculations than when plotted in the usual way with speed and tractive effort as ordinates and amperes as abscissæ, which latter form involves for the most part, reading across from one curve to the other.

Train Resistance. For train resistance with ordinary brass bearings the Armstong formula has been generally accepted by railway men. It is required to give a formula that will represent equally well the train resistance of a car or train with antifriction bearings. Considering the Armstrong formula, the last term, referring to wind resistance, is independent of the type of bearing and therefore remains unchanged, while the first two terms, which represent track and bearing resistance (which have not so far been satisfactorily separated) will be decreased. There then remains the usual method of deriving an empirical formula, viz; by making an assumption and testing its truth against measured results. By this process, one-third of that amount given by the Armstrong formula for the total of the first two terms has been found to be substantially accurate.

As a check on this deduced formula, we have, for the tested saving over the $4\frac{3}{4}$-mile stretch of track between stops, (in which the actions of the motorman are less significant and therefore the results more reliable), see page 1165;

0.48 kw-hr. per car mile and 1% loss in time in one instance
and 0.52 " " " " " 3% " " " " another "

The calculated saving, assuming 80 per cent motor efficiency and equal running times, is[1] 0.54 kw-hr., or 0.51 kw-hr. if 85 per cent motor efficiency is assumed.

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1. Saving per car mile

$$= \frac{2}{3}\left(\frac{50}{\sqrt{W}} + 0.03S\right) \times W \times (5280 \text{ ft.} - \text{Proportion of braking dist.}) \div \text{motor efficiency.}$$

$$= 6.14 \text{ lbs.} \times 36.3 \text{ tons} \times 5210 \text{ ft.} \div 0.80 = 1{,}450{,}000 \text{ ft.-lb.} = 0.54 \text{ kw-hr.}$$

Weight of car (W) = 36.3 tons; average speed (S) = 30 miles per hr.; and braking starts at a speed of about 30 miles per hr., and is at a rate of 2 miles per hr. per sec., therefore the braking distance is 330 ft. and the proportion of this for 1 mile is $330 \div 4\frac{3}{4} = 70$ ft.

Fig. 4 gives train resistance. The upper curve is according to the Armstrong formula, while the lower curve represents approximately the resistance for a car with anti-friction bearings on the main journals.

Acceleration. Combining these train resistance curves of Fig. 4 with the motor characteristic curves of Fig. 5 and allowing for the effect of rotating parts, (it requiring a force of 98.2 lb. per ton of dead weight of car to produce an acceleration of one mile per hour per second),[1] we have acceleration curves for ball and plain bearing cars as shown in Fig. 6. At first glance it would appear that very little difference existed between the accelerations for the two types of cars, but the fallacy of this impression is evident from a closer study. During the first 20 seconds, in which a speed of 25 miles per hour (a little

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1. As explained in Carter's paper entitled "Technical Considerations in Electric Railway Engineering" before the I. E. E., Jan. 25, 1906, the inertia of the rotating parts may be combined with the weight of the train to give the effective weight.

If w be the weight of a wheel, r its radius at the tread and k its radius of gyration, the increment of weight due to the rotation of the wheel is $w\left(\frac{k}{r}\right)^2$.

In an average steel railway wheel $(k/r)^2 = 0.6$. Similarly, for an armature of weight w' and gear ratio n, the increment of weight is

$$w'\left(\frac{k'}{r}n\right)^2 = w'\left(\frac{k'}{r'}\frac{r'}{r}n\right)^2$$

For a continuous current armature $(k'/r')^2 = 0.5$ approximately.
also $r'/r = 0.5$ "
For a weight of car wheel, 600 lb.
" " armature, 800 lb.
" " gear ratio, 2.625

whence total equivalent weight in translation corresponding to rotation of eight wheels and four armatures

$= 0.6 \times 600 \times 8 + 0.125 \times (2.625)^2 \times 800 \times 4 = 5600$ lb. $= 2.8$ tons.

Since force = mass $\times$ acceleration

Force required to give a weight of 1 ton an acceleration of 1 mile per hr., per sec. (or 1.467 ft. per sec. per sec.)

$$= \frac{2000}{32.16} \times 1.467 = 91.2 \text{ lb.}$$

since the rotating parts of the car produce an effective weight for translation of $36.3 + 2.8$ tons $= 39.1$ tons.

The accelerating force per ton of dead weight has to be increased in the proportion of 36.3 to 39.1 or from 91.2 to 98.2 lb. per ton.

more than half speed) is attained, the advantages with anti-friction bearings is less important than during the latter part of the acceleration period, which consumes the greater portion of the time. In this latter period the ball bearing car has an advantage of 25 to 100 per cent over the plain bearing car. This is readily noted by an inspection of the per cent curve on Fig. 6

Coasting. In order to see definitely the conditions of coast-

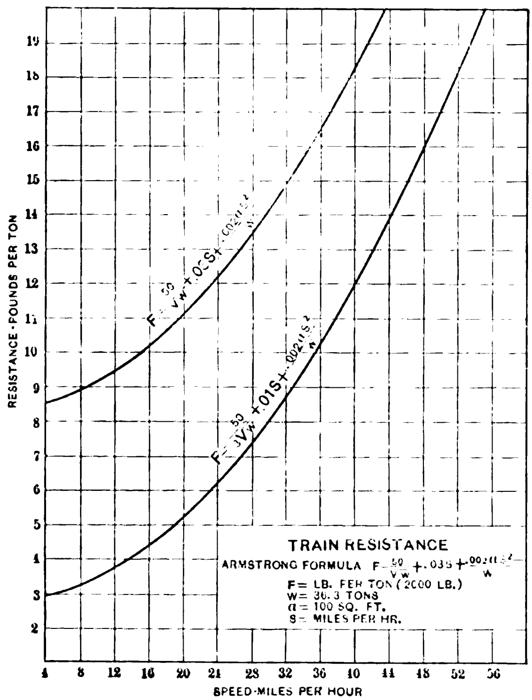

FIG. 4—Train resistance

ing and the amount of benefit to be derived therefrom from an energy point of view, Fig. 7 has been drawn. This refers to a plain bearing car making a run of 2,900 ft. It will be seen that, with the conditions of acceleration and braking observed from test, the least time in which the car can cover this distance is 82 seconds, which admits of no coasting. Under such conditions the car consumes 110 watt-hours per ton-mile. If it is satisfactory to make this same run in 83 seconds, a 16-second coast is admissible, bringing down the energy consumption

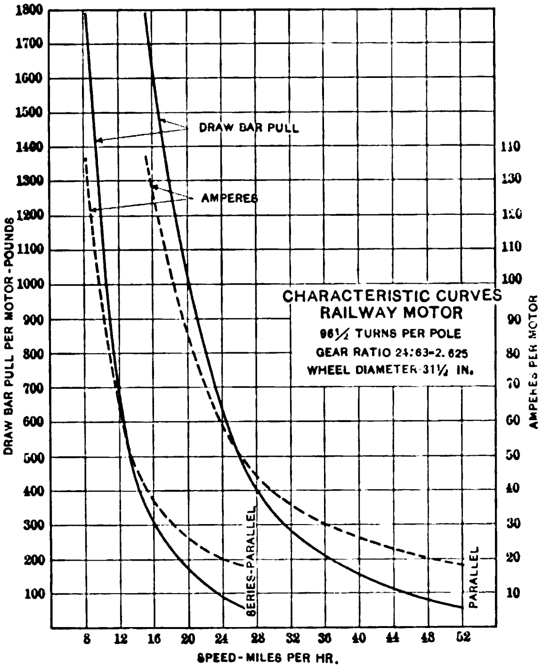

FIG 5—Moto · characteristics

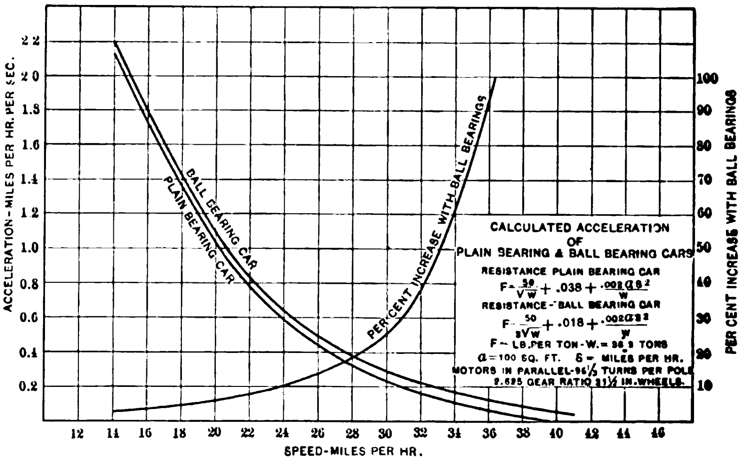

FIG. 6—Acceleration curves

to 94 watt-hours per ton mile or a saving of 17 per cent. If again it is satisfactory to make this run in 85 seconds, 30 seconds coasting may be employed and a saving of 25 per cent attained in energy consumption.

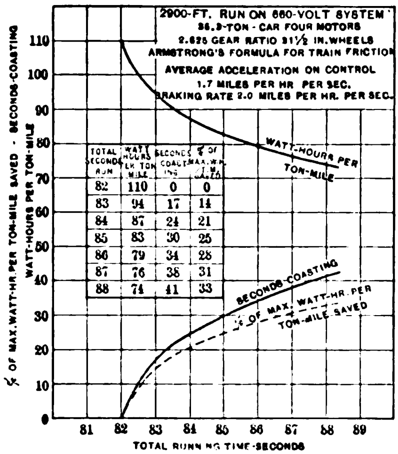

FIG. 7—Energy consumed with plain bearings

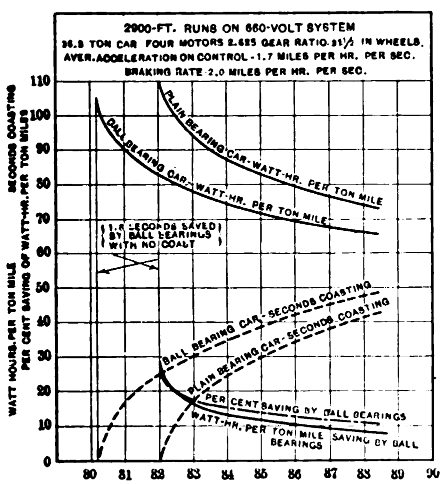

FIG. 8—Energy saved with ball bearings

Passing to Fig. 8, the same curves as in Fig. 7 are redrawn for the plain bearing car together with the comparative curves for the ball bearing car. If the results are compared on any vertical line, taking say, 84 seconds for the

total running time, the true comparison in energy consumption between the plain bearing car and the ball bearing car is given by the difference in the ordinates of the two. The curve giving the difference between these two is shown at the bottom of Fig. 8 as "watt-hours per ton mile saving with ball bearings" which, for 84 seconds is 13 watt-hours or 15 per cent while the durations of the coasting periods are 24 seconds to 35 seconds; which means that with a ball bearing car there is a further advantage from the additional 11 seconds coast between stops, because the riding is made more pleasant for the passengers, during this period which amounts to 12 per cent of the running time.

It is important to point out that unless curves are compared under similar running times, the percentage difference between the two types of cars may be small or, possibly, reversed. That these facts are overlooked in making tests shows their importance is not clearly understood. For instance, suppose the ball bearing car makes the run in 81 seconds and the plain bearing car in 83 seconds, each car should then coast 17 seconds over practically the same distance. The energy saving would only be 4½ per cent and the saving in time, 2½ per cent.

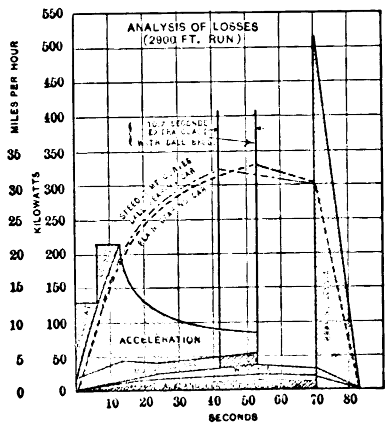

FIG. 9—Analyses of runs

Instructions to Motormen. It is often claimed that it is impossible to make the motormen carry out the coasting as desired. They should not be expected to do it unless they are instructed. As to whether this instruction is worth while or not is readily borne out by the above statement of savings in reference to the Philadelphia Subway. This is also emphasized by the importance which the Interborough Rapid Transit Company of New York is attaching to it, by the employment of coasting registers on the cars.[1] Through these coasting registers the motormen have some tangible means of realizing what has happened and are more impressed by the importance

1. *Electric Railway Journal*, Oct. 30, 1909, p. 938.

of their operation. If the superintendent of the railway company is not sufficiently concerned to give careful instructions to the motormen regarding the value of coasting, it is hardly likely that the motormen will be interested in making an effort to operate economically.

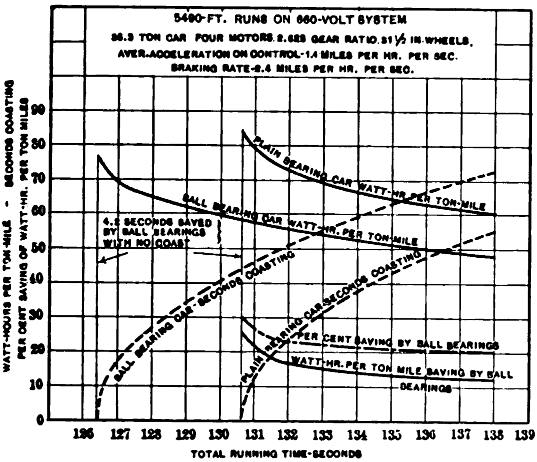

FIG 10—Energy saved with ball bearings

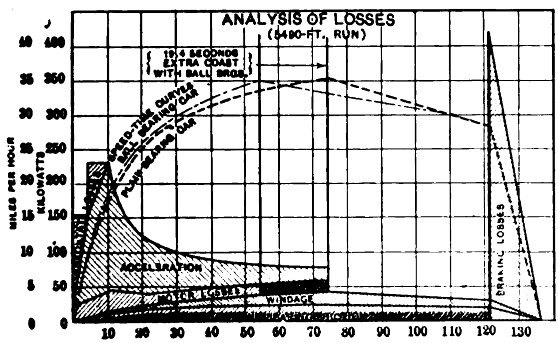

FIG. 11—Analyses of runs

Analyses of Calculated Runs. Fig. 9 is an analysis of the runs with ball and plain bearing cars over a distance of 2,900 ft., in 83 seconds. The areas show the distribution of energy consumption at the car. The increased amount of coasting, of the ball bearing car, viz., 11 seconds means that the controller is shut off that much earlier and consequently the motor losses,

which are a high percentage of the motor output at high speed because of low current consumption, are reduced. The greater saving, however, results in the elimination of the bearing friction, amounting to about two-thirds of that section of the loss area appearing at the bottom of the diagram. The figures representing these elements of loss are given in the table below:

2900-FT. RUN IN 83 SECONDS. FOUR MOTORS GEAR RATIO 2.625 WEIGHT OF CAR 36.3 TONS

Losses in	Watt-hours		Saving Per cent
	Plain bearings	Ball bearings	
Starting resistance	200	190	5
Windage	165	165	0
Track and bearings	330	110	67
Braking	905	850	6
Motors	275	245	11
Total	1,875	1,560	17 or 0.57 kw-hr. per car mile

Fig. 10 and 11 are similar to Fig. 8 and 9 respectively except that they represent comparative analyses of 5,190-ft. runs.

The table of comparative analyses of these longer runs is given below.

5490-FT. RUN IN 136 SECONDS. FOUR MOTORS. GEAR RATIO 2.625. WEIGHT OF CAR 36.3 TONS

Losses in	Watt hours		Saving per cent
	Plain bearings	Ball bearings	
Starting resistance	170	165	3
Windage	380	375	1
Track and bearings	655	215	67
Braking	780	830	-6
Motors	395	300	24
Total	2,380	1,885	21 or 0.48 kw-hr. per car mile

It will be noted that the saving in watt-hours per car-mile in each case is about 0.5 kw.-hr. irrespective of the number of

stops, but that in short runs the amount represents 17 per cent and in the long runs 21 per cent.

Analyses of Test Runs. The following are the average results per trip over 15.2 miles, the same motorman being employed for comparative runs:

FIRST SET OF TESTS. SPECIAL TRIPS WITHOUT PASSENGERS—20 STOPS—NORMAL RUNNING TIME

Car bearings	Time running with power on minutes	Average speed in motion miles per hour	Loss in rheostat kw-hr.	Loss in motors and gears kw-hr.	Loss in train resistance and brakes kw-hr.	Total kw-hr. for traction
Plain..........	27.07	25.4	3.62	8.11	32.43	44.16
Ball...........	26.08	25.2	3.30	7.04	28.18	38.52
Difference......	4 per cent	1 per cent	9 per cent	13 per cent	13 per cent	13 per cent
In favor of....	Ball	Plain	Ball	Ball	Ball	Ball

In the above an equal number of stops has been made by each type of car. The average speeds of the car have been maintained equal within 1 per cent in favor of the plain bearing car, while a saving of 13 per cent has been obtained in energy and 4 per cent less time running with the power on. An analysis of the details of these tests shows that the braking rate on the plain bearing car was about 2.4 miles per hour per second, while on the ball bearing car the rate was less. Consequently the saving in time has occurred on the plain bearing car at the expense of a higher rate of breaking, meaning discomfort to the passengers and an additional strain on the brakes. Also on account of the inequality of braking rates, the measured saving in energy with the antifriction bearing car is less. The reason for this is evident from an inspection of the curves Fig. 7, and the accompanying explanation already given under the heading " Coasting ".

The losses in the starting resistance were determined by observation of the controller operations. The number of times the controller was operated and in each case the number of seconds on control were recorded; also tests were made to determine the average current for the various times on control. This test gave the following figures from which these losses were determined:

OBSERVATIONS FROM WHICH RHEOSTAT LOSS CALCULATIONS WERE MADE

Starting current—amperes per motor......	65	75	85	95	105	125
Time on control (series-parallel and parallel sec)................................	24	18	14½	12½	10½	6½
Aver. line voltage (series parallel).........	620	620	610	600	590	580
Aver. line voltage (parallel)..............	580	570	560	540	520	500

Example.

Time on control, 18 sec., 9 in series-parallel and 9 in parallel.
Average current per motor, 75 amperes.
Average voltage, series parallel, 620; parallel 570.
Resistance of 1 motor 0.315 ohms –(4 motors per car).
Approximate loss in starting resistance for

$$\text{Series-parallel} = \frac{75\,(620 - 0.315 \times 75 \times 2)}{1000 \times 2} \times \frac{9 \times 2}{3600} = 0.11 \text{ kw-hr.}$$

$$\text{Parallel} = \frac{75\,(570 - 620 \times \tfrac{1}{2})}{1000 \times 2} \times \frac{9 \times 4}{3600} = 0.10 \text{ kw-hr.}$$

By adding up all the individual losses for each controller operation the total loss on the rheostat was determined. Subtracting this rheostat loss from the total input, as recorded by the watt-meter, the remainder is the input to the motors. The efficiency of the motors has been taken at 80 per cent, whence the total loss in motors and gears, and also the output of the motors; this latter represents the loss in train resistance and brakes. An effort was made to separate the train resistance loss from the brake loss by recording the speed at which braking was commenced and in that way determining the kinetic energy wasted in brakes; the motor output minus this must then have been used in overcoming train resistance. Owing to the fact that no indicator was attached to the air brake handle to indicate at what moment the brakes were put on, the results in this case have not been considered sufficiently satisfactory to make an effort to separate the train resistance losses from those in the brakes.

SECOND SETS OF TEST

Car bearings	Time running with power on minutes	Average speed in motion miles per hour	Loss in rheostat kw-hr.	Loss in motors and gears kw-hr.	Loss in train resistance and brakes kw-hr.	Total kw-hr. for traction
Plain..........	25.04	28.3	1.81	6.93	27.71	36.45
Ball...........	22.44	28.7	1.76	5.77	23.08	30.61
Difference.....	9 per cent	1 per cent	3 per cent	17 per cent	17 per cent	16 per cent
In favor of....	Ball	Ball	Ball	Ball	Ball	Ball

It will be noted that, with the greater distance between stops, the saving as an absolute amount is about the same, but that as a percentage it is increased. The amount of time with the current on is 9 per cent less with a ball bearing car than with a plain bearing car, while the speed of the former is slightly in excess of that of the latter. Again the rate of braking was found to be greater with the plain bearing car, so that the saving in energy is not so great as it would otherwise be if the braking rates had been the same for each type of car and the running times then equalized by additional coasting with the ball bearing car.

This tendency to operate all cars alike as regards coasting, placing the possibilities of a ball bearing car at a disadvantage, is to be expected when a motorman has to operate one ball bearing car in conjunction with a number of plain bearing cars.

Reverting to the energy consumption over the 4⅜-mile stretch of track between Atlantic City and Pleasantville in which no stop is made, the following figures give the savings together with the conditions of speed.

FIRST SET OF TESTS

Type of bearings	Average speed	Kw-hr. per car-mile
Plain	30.3	2.30
Ball	29.9	1.82
Difference	1 per cent	0.48 or 21 per cent
In favor of	Plain	Ball

For the second series of tests the results are similar and are as follows:

SECOND SET OF TESTS

Type of bearing	Average speed	Kw-hr. per car-mile
Plain	30.0	2.28
Ball	30.8	1.76
Difference	3 per cent	0.52 or 23 per cent
In favor of	Ball	Ball

These tests show respectively a saving of .48 and .52 kw-hr. per car mile of 21 and 23 per cent, which closely approximate the saving calculated from the special formula, Fig. 4.

In further support of these results it may be interesting to note the record of tests on the Eastern Bengal State Railway, of India, recorded by Prof. Carus-Wilson,[1] of two six-coach passenger trains, one fitted with brass bearings and one with roller bearings. The cars alone weighed 166.5 long tons and the engine 85.5 long tons or 252 tons per train. The average running speed was 31.4 miles per hr. The results obtained are given in the following table:

	Brass bearings	Roller bearings
Train mileage	873	873
Coal consumed	28,342 lb.	24,840 lb.
Water	217,240 "	191,630 "
Coal ratio	100 per cent	87.5 per cent
Water "	100 "	88.2 "

In the above table the saving due to the roller bearings is 12 per cent. In this case, however, the locomotive, which consumes a large proportion of the fuel in order to propel itself, had ordinary plain bearings in each instance, and necessarily reduced the saving as a percentage on the whole train.

Mechanical Qualities and Reliability of Antifriction Bearings

The reliability of some innovation which is a radical departure from standard practice is naturally a main issue. As is well known, there are two distinct types of antifriction bearings, *viz.*; ball and roller, which, although similar from an antifriction standpoint, differ mechanically and should therefore receive separate consideration when the question of reliability is concerned. They are perhaps best treated by the use of examples.

The United Traction Co. of Albany, in April 1890, put into operation 32 roller bearing cars, which were most satisfactory from an energy saving standpoint, but sooner or later the long rollers became bent and then quickly cut.

Some roller bearings with rollers 7¾ in. long, put in service on the Western Bengal State Railways, in January 1899, on passenger cars, were repaired after 165,000 miles service (4½ years), but discarded in 1906 on account of taper wear that had

1. Paper entitled "Predetermination of Train Resistance", Proceedings of British Institution of Civil Engineers, Vol. LCXXI, p. 28.

taken place on the rollers and journals. Ordinary brass bearings were substituted.

Other such experiences of recent date have shown similar results, from which it is evident that long rollers are unsatisfactory mechanically where continuous service is required. However, if the rollers are made short, they will less easily become bent, but will still tend to wear taper. If they are made so short that their length is equal to their diameter and their ends are rounded off, we have balls, which, from experience with properly selected sizes, will neither deform nor wear ap-

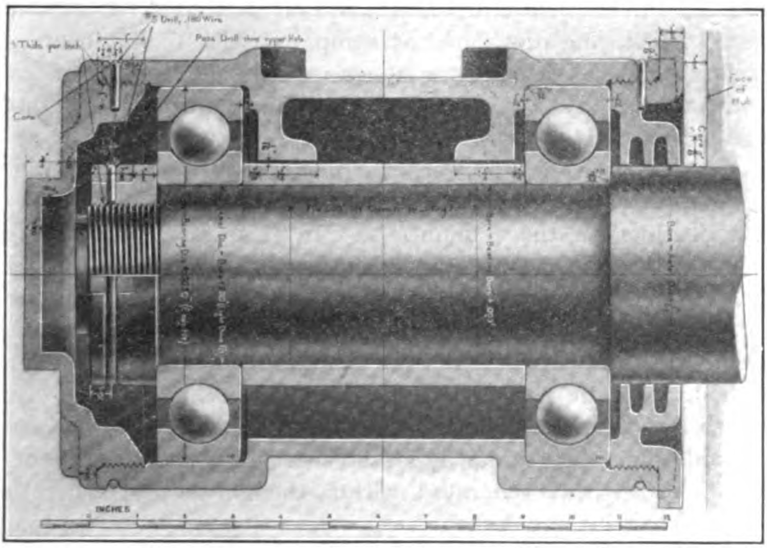

FIG. 12—Cross section of ball bearing

preciably out of shape, with reasonable protection from grit.

The ball bearings on the Atlantic City car and other railway equipment, including mining and street railway motors, that have been equipped with this type of ball bearing, have not shown any appreciable radial wear after nearly two years' service, have, not had any repairs and, with the exception of mining motors, have been lubricated something less than twice a year.

Fig. 12 shows the general arrangement of ball bearings on a main car journal, and incidently makes the figures for costs which follow more definite.

Temperature Rise in the Bearings. With regard to hot bearings the writer's experience, confirmed by information obtained by conversation with superintendents and master mechanics in the various states, is that city railways on account of their relatively low speed are not troubled much with hot bearings; but interurban roads find such occurrences more common. Further, even though the hot bearings may not always result in delays, still when they occur on motors they prevent satisfactory radiation, producing defective insulation, especially in fields coil.

In a recent series of tests made by a railway company, the average difference in temperature rise on field coils for motors with ball bearing armatures as compared with babbit bearing armatures was 6½ deg. cent or 20 per cent. These tests extended over nine test days with each type of car and continued for about eight consecutive hours each day.

A manufacturing firm recently made a test on a 125-h.p. single-phase motor to determine the heating effect of the babbitt bearings on the commutator. In this test a motor was operated dead on a car, being driven by its gearing for 4½ hours on a one mile section of track; the rise in temperature on the commutator with the brushes removed was 30 deg. cent., while, with the brushes on the commutator under a similar 4½-hour test, the rise amounted to 60 deg. cent.

The ball bearings on the main journals of the Atlantic City car will operate continuously all day without a rise in temperature, due to heat generated within themselves, sufficient to be detected by the hand.

A test was made on two 65-h.p., 500-volt railway motors, similar in every respect, except that one had ball and the other babbitted armature bearings, in which the motors were run light on 220 volts.[1] After about three hours of continuous running, the temperature rise of the ball bearings, practically all of which was due to conduction of heat, was 30 deg. cent. to 40 deg. cent. less than that of the plain bearings, notwithstanding the fact that the ball bearing armature assumed a speed of 1700 rev. per. min. and the plain bearing armature only 1000 rev. per min. The babbitted armature bearings were repacked and oiled by a railway company's regular employees previous to this run, while the ball bearings on the commutator end was drained of oil but not wiped.

1. *Electric Railway Journal*, Oct. 8, 1909, p. 823.

Commercial Aspects. In order to cover all phases of the anti-friction bearing proposition, the following statements of cost are given. These illustrate in a general way the commercial situation, for interurban cars of the Atlantic City type. They refer, however, only to the more definite quantities, as the less definite, but oftentimes more important which embrace convenience and lack of attention, cannot be so satisfactorily recorded.

I. *Energy Saving.* From the tests it is evident that at least .5 kw-hr. per car-mile can be saved by anti-frictionizing, hence with an annual car-mileage of 60,000 (or 200 miles per day and nine weeks layoff per year) and assuming 1 cent per kw-hr. at the power house with 88 per cent efficiency of trolley line, this amounts to

0.5 kw-hr. $\times$ 60,000 miles $\times$ 1 cent $\div$ 88 per cent. = $340.00

II. *Journal Box.*

	Ball type	Plain type		
Castings—box	$ 5.00	$ 6.50		
wedge	—	.75		
Machine work	9.00	—		
Assembling, packing, etc	2.00	.75		
Total per box	$16.00	$ 8.00		
" " car	128.00	64.00		
Difference per car			$64.00	
Interest on investment at 5 per cent				$3.20
Depreciation of annuity (at 4 per cent compound interest 15 year life) = 5 per cent				3.20

III. *Bearings.*

	Ball type	Plain type		
Two per box (240,000 miles or 4 yr. life)	$70.00			
two brasses per journal for same distance (life 120,000 miles each)		$6.00		
one additional bearing change	—	1.00		
Total per box	$70.00	$ 7.00		
" " car	560.00	56.00		
Difference			$504.00	
Interest on investment at 5 per cent				$25.20
Depreciation annuity at 4 per cent compound interest, 4 yr. life = 23.5 per cent				118.40

IV. *Summary.*

Total increase in annual cost	150.00
Net saving	190.00

representing 33 per cent on additional outlay or 27½ per cent on total outlay in cases where plain bearing equipment has already been bought.

Outside Views. Figures confirming tests made on the Atlantic City and Shore R.R. will be found in an article entitled "Bearing Friction and Power Consumption"[2] by M. V. Ayres, Electrical Engineer of the Boston & Worcester Street Railway Co. which records a saving of 27 per cent on a half-mile run with approximately the same weight of car as in the above tests. Mr. Ayres shows that this saving would result if the combined track and bearing friction were eliminated. This represents 0.9 kw-hr. per car-mile, the major part of which he states can be attributed to bearing rather than track friction. He adds, "If it is possible to reduce bearing friction by means of ball bearings by an amount sufficient to reduce train resistance 8 lb. per ton, and I believe that this is a safe assumption for rapid transit work, this would produce a saving of 20.8 watt-hours per ton-mile. For a 25-ton car running 200 miles per day this would amount to 38,000 kw-hr. per year, worth, at 1½ cents per kw.-hr., $570 per year".

CONCLUSIONS.

The economies to be derived from coasting, explained in this report quantitatively, are:

1. Additional comfort to passengers.

2. Decreased maintenance charges of brakes and also motors due to lower temperature.

3. Saving in energy.

The above tests show that not only are all these advantages appreciably augmented by antifriction bearings, but also supplemented by increased reliability, meaning decrease in time of equipment out of service, avoidance of hot journals, saving of lubrication expense, and last but most important, acquisition of traffic. For it would seem that far and away above what might accrue from the possible energy saving is the fact that the ball bearings give no trouble and require lubricating not more than twice a year. The full advantages obtained with ball bearings, properly selected and housed, can only be appreciated by their actual use.

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2. *Electric Railway Journal*, Aug. 21, 1909, p. 286.

See also discussion by Cyril J. Hopkins of paper Electrification of Railways, Engineers' Club Journal, Philadelphia, delivered April 1909.

NOTE

The following paper is to be read at the 27th annual convention of the American Institute of Electrical Engineers at **Jefferson, N. H., June 28 – July 1, 1910.** This paper is to be presented under the auspices of the High Tension Transmission Committee of the Institute. All those connected with the Institute and desiring to take part in the discussion of this paper may do so by being present at the meeting; or, if this is not possible, by sending in a written contribution.

Written contributions will be read at the meeting, time permitting, for which they are intended, either in full, in abstract, or as a part of a general statement giving a summary of the views of those taking the same position in the matter.

The principal object in getting out the paper in advance of the meeting is to enable and encourage those not in a position to attend the meetings to take part in the discussion by mail.

Contributions to the discussion of this paper should be mailed to **Ralph D. Mershon, Chairman, High Tension Transmission Committee, 60 Wall Street, New York,** so that they will be received not later than June 23, 1910.

(TOBEY)

A paper to be presented at the 27th Annual Convention of the American Institute of Electrical Engineers, Jefferson, N. H., June 27-30, 1910.

DIELECTRIC STRENGTH OF OIL

BY H. W. TOBEY

A large part of the apparatus comprising the equipment of electric power transmitting systems depends, for its safe and successful operation, on oil. This fact continues to grow in importance from year to year as the size of the units in which it is used increases, the operating voltages become higher, and the conditions more severe.

Not only must this material be of such consistency that it will circulate freely and so carry heat from the sources where it is generated to external cooling surfaces, but it must be free from any impurities which would injure the insulation or active material of which the apparatus is built; and above all, it must withstand voltage stresses without interruption, year in and year out. Failure to meet these conditions, sooner or later, means failure of the apparatus with which it is used.

It is the purpose of the present paper to outline some of the more important characteristics of oil which fulfil these conditions with special reference to dielectric strength. These characteristics are exemplified throughout by curves and data which have been collected from the results of extensive tests and investigations carried on during a number of years.

Nature of Insulating Oils

The oils now most commonly used for insulating purposes are obtained from crude petroleum by " fractional " distillation this being entirely distinct from the method known as " cracking " distillation, used for obtaining the greatest yield for burning oils. Fractional distillation is carried on in such a way as to yield a sweet, unburned residual oil, while distillates of higher

boiling points, after being subjected to various other manipulations become what may be called insulating oils. The process is carried on in such a manner as to preserve the hydrocarbons in their natural form. It is probable that they are composed chiefly of bodies having the general formula $C_n H_{2n+2}$, though without doubt they contain also bodies made up of $C_n H_{2n}$.

This brief description gives an idea of the method used in obtaining insulating oils, together with their composition. The characteristics, such as flashing and burning points, viscosity, etc., depend, of course, upon the limits worked to during the process of distillation and refining. The following data, however, indicates what may be expected from a medium and from a light grade oil.

	Medium	Light
Flashing temperature	180° to 190° cent	130° to 140° cent
Burning temperature	205 to 215	140 to 150
Cold test	−10 to −15	−15 to −20
Specific gravity at 13.5 deg. cent	0.865 to 0.870	0.845 to 0.850
Viscosity at 40 deg. cent (Saybolt test)	100 to 110 sec.	40 to 50 sec.
Acid, alkali, sulphur, moisture	None	None

When free from moisture both have the same dielectric strength (45,000 to 50,000 volts, sine wave, between ½ in. discs placed 2/10 in. apart.)

The two most noticeable differences are in the fire and viscosity tests. The medium grade has a flashing temperature about 50 deg. above that of the lighter oil and a burning temperature about 60 deg. above. As to viscosity, a given quantity of the medium grade oil requires about two-and-one-half times as long to pass through a given orifice as does the light grade, conditions as to temperature, etc., of course, being the same.

It is usually customary for reasons of design to use the medium grade in apparatus such as self-cooled transformers, for example, in which the temperature of the oil at the top, due to overloads, etc., may reach fairly high values, the lighter grade being employed in apparatus such as water-cooled transformers, for instance, where the temperature may be more readily controlled. By this means the maximum possible temperature of the oil will in either case, be well below the flash and burning points. Under these conditions, too, it would require a long time for any

external source of heat, such as a fire in the building, to raise the temperature to a point such that the oil would take fire and burn. Combustion would not be supported until the temperature had been raised above the burning point.

Factors which cause Variation of Dielectric Strength

In taking up the question of dielectric strength and the factors which cause it to vary, it will be well, in order to avoid possible confusion, first to mention the considerations upon which all remarks and tests contained in the paper are based.

The voltage under which the oil breaks down, while under electric stress, depends upon the maximum value of the electromotive force, not upon the square-root-of-mean-square value. This is a long established fact. If, however, the shape of the electromotive force wave is not distorted during test, the ratio between maximum and square-root-of-mean-square values remains constant, and the latter may be used as a basis for measurements. This applies to all voltage values mentioned in the paper. The ratio between these two values, however, differs with every wave-shape, therefore, if the voltage is to be determined in the usual way from voltmeter readings, it is absolutely essential to have the shape of the e.m.f. wave well defined in order to correctly interpret the results. Moreover, the shape should remain the same throughout all tests and for all voltages. This condition existed during the tests mentioned in the paper. Square-root-of-mean-square values are recorded throughout.

All tests referred to here, were carried on under as nearly uniform conditions as possible. Sine-wave generators furnished the energy. Voltage variation was obtained by field control, in connection with series multiple windings on the low tension side of the testing transformer. No series resistance was used in the controlling system.

According to the A. I. E. E. standard for determining striking distances in air, a non-inductive resistance of one-half ohm per volt volt should be placed in series with each terminal of the spark-gap to prevent surges which might occur at the time of breakdown. It was suggested that the same precaution might be advisable in connection with the tests between various shaped terminals in oil. This was therefore carefully tried out with a disk and needle point. These terminals give a straight line curve up to a comparatively high voltage and therefore furnish a ready means of checking. Two sets of readings were taken, with increasing dis-

tances and for voltages up to 180,000. In one set, a water resistance adjustable to one-half ohm per volt was placed in series with each terminal, while in the other set, the transformer leads were connected directly to the terminals without intervening resistance. The results were identical. All other tests were therefore made without series resistance.

As far as possible, tests were made of uniform duration, low voltage first being applied and increased gradually until breakdown occurred, this usually requiring from five to twenty-five seconds depending on the magnitude of the voltage. In this way the question of time was largely eliminated, although it is probable that the insulating qualities of oil do not change materially under continued stress. This cannot be said to hold true, though, during short intervals, fractions of a second, for example, for in such cases time has an important bearing on the result.

For the sake of uniformity, the same frequency was used throughout, although it is believed that the variations in breakdown values are comparatively small over the range of present commercial frequencies.

The difficulties in carrying on an investigation of this kind are great, owing to the number of variables which may creep into the work. Even with apparently identical conditions, it is sometimes difficult to duplicate results. An enormous number of tests were therefore necessary in order to obtain reliable figures. Every point used in plotting the curves reproduced in the paper, is the result, not of one test, but of a great many, from which an average was taken.

Shape of Terminals

The disruptive strength of oil depends to a large extent on the shape of terminals between which it is tested. For the sake of comparison, assume a uniform grade of oil which is clean and free from moisture. The voltage necessary to break through a given distance between two spheres is less than between two disks. That required to disrupt the oil between needle points is less than between two spheres, etc.

The reason for this is at once apparent from diagrams, Figs. 1 to 5. By referring to these and to the curves, Fig. 6, it will be seen that the shapes of terminals which cause the lowest breakdown values, are those which allow the greatest concentration of electric stress at one or both terminals. In other

words, the terminal is surrounded by a zone of oil across which the stress is greater than in the next succeeding zone. The oil in the former is strained beyond its strength and breaks down. As soon as this occurs the stress is transferred to the next zone and this breaks, and so on across the entire gap. In actual practice, of course, these ruptures occur in such rapid succession that they are virtually simultaneous.

When the distribution of flux is perfectly uniform, as for exam-

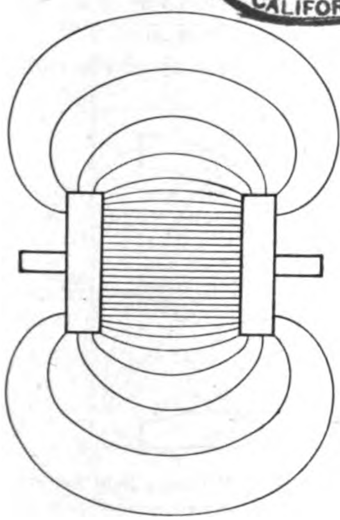


FIG. 1—Electrostatic field between disks

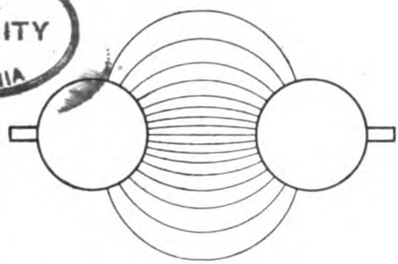


FIG. 2—Electrostatic field between spheres

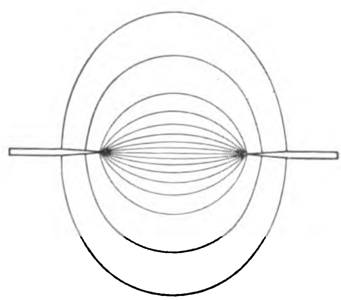


FIG. 3—Electrostatic field between needle points

ple, between large disks placed near together, the average and maximum densities are the same. This no longer holds where the field is distorted, for in this case the stress across one section of the gap, as already indicated, may be very much greater than across the remainder. The distances between terminals may have been exactly the same, yet the second gap will break down at lower voltage because the oil in one section of it was strained beyond its breakdown point. This condition is illustrated in the diagrams, Fig. 1 to 5, which were drawn by first plotting the

equipotential lines and afterwards filling in the lines of force, the latter of course being normal to the former at every intersection. The accuracy of the lines was checked in a somewhat novel manner, as follows:

It is well known that the laws governing the distribution of magnetic fields of force are in many respects the same as those governing electrostatic fields. Iron terminals were therefore produced, resembling those shown in Figs, 1 to 5. These were placed, two at a time, on a plane of paper over the poles of an electro-magnet, and iron filings sprinkled onto the paper. The arrangement of the filings both as to direction and concentration, gave a very clear conception of the distribution of an electrostatic field of force between similar terminals in oil.

Again, referring to the curves, Fig. 6, attention should be called

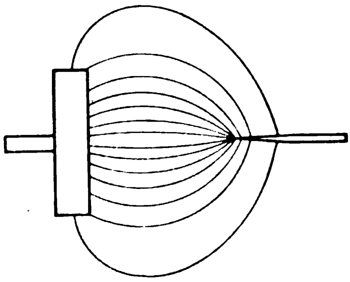


Fig. 4—Electrostatic field between disk and needle points

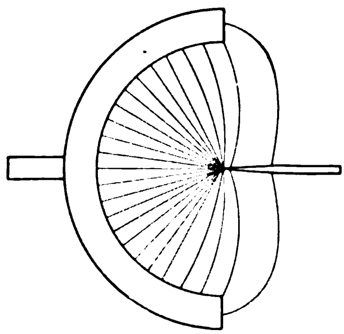


Fig. 5—Electrostatic field between hollow hemisphere and needle points

to the fact that the size of each pair of terminals was the same throughout the range of voltage covered. This means that the distribution of the lines of force in the electrostatic field changed slightly with each setting. In order to determine definitely therefore, the effect of shape of terminal on the breakdown strength of oil for a definite distribution of flux, it would be necessary to use many different sizes so that the dimensions of the terminals would bear a definite relation to the length of gap. The only curve which would not be affected, would be the one referred to needle points. The distribution of the lines of force in this case would be the same for all distances, unless perhaps the rounded shape of the points would have an effect at extremely small distances, small fractions of an inch, for example.

Oil Testing Apparatus

The two standards now most commonly used for oil testing are composed of pairs of terminals of definite shape, arranged in a suitable receptacle for holding the oil.

In one of these, the testing terminals consist of ½ in. diameter brass balls fastened to 3/16-in. rods. These are placed vertically in a glass tube and arranged so that they may be adjusted for different distances, 0.15-in. usually being considered standard. Average dry oil should not break down at less than 30,000 volts.*

The other of the two mentioned standards is composed of two ½-in. brass disks, mounted on ⅜-in. rods and arranged hori-

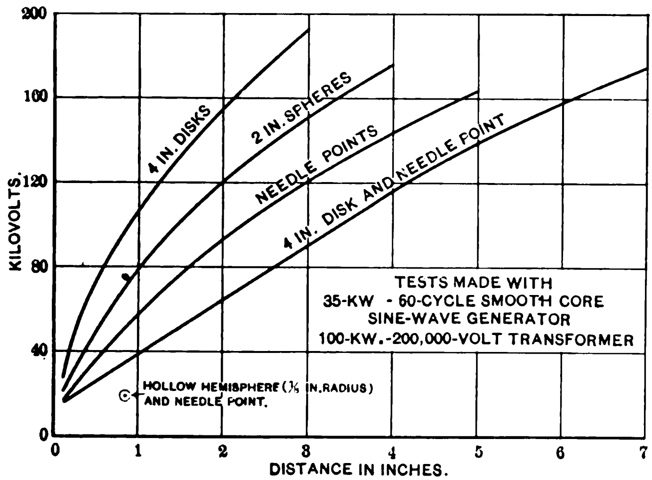


Fig 6—Disruptive voltage of dry oil measured between variously shaped terminals

zontally in a receptacle for holding the oil. The disks may be adjusted for different distances although, 2/10-in. has been adopted as standard. Dry oil should not break down in this at less than 45,000 to 50,000 volts, with a sine-wave e.m.f.

The disk form of gap was employed in making the various tests mentioned in the paper. It was preferred because of its uniform electrostatic field, and also on account of the fairly large amount of oil which would be subjected to test.

* Articles by C. E. Skinner, on "Transformer Oil," *Electric Journal*, May, 1904; and by S. M. Kintner on "The Testing of Transformer Oil," *Electric Journal*, October, 1906.

Particles of moisture or other impurities could be detected over a considerable area.

Effect of Temperature

The dielectric strength of oil does not vary greatly with moderate changes in temperature. One sample tested, for example, stood an average of 52,000 volts at 60 deg. cent. before breaking, and 45,500 or only 10 per cent less, at 20 deg. cent., while at slightly above zero its value had dropped only to 44,000 volts.

Upon congealing, however, as the temperature drops below

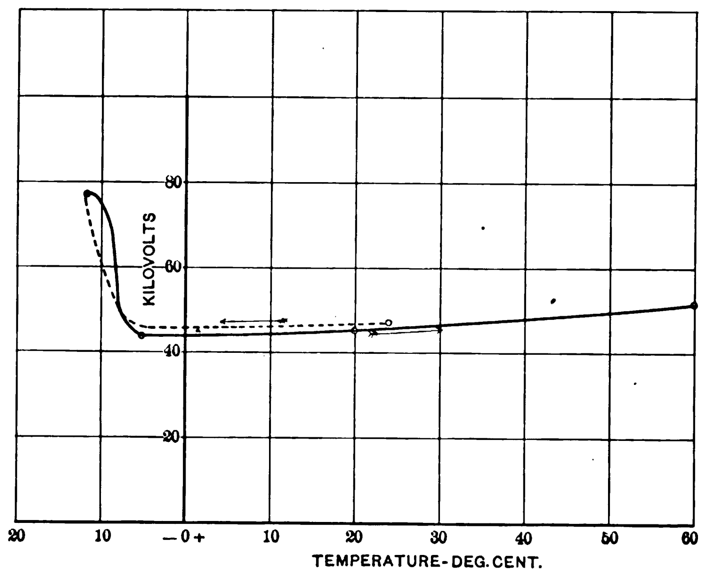


Fig. 7—Effect of temperature on dielectric strength

the freezing point of the oil, the dielectric strength increases with great rapidity, in some cases reaching a value 60 to 80 per cent higher than that just before the freezing point was passed. In the example just referred to, the dielectric strength rose to approximately 77,000 volts, or an increase above 44,000 of 75 per cent.

On heating, the strength drops to the value it had just before freezing, although it is usually necessary to raise the temperature considerably above the freezing point before this occurs. In other words, changes in strength lag behind changes in temper-

ature. Continued heating will finally restore the dielectric strength to its initial value. The accompanying curve, Fig. 7, indicates the cycles through which these changes take place. This may be considered typical for one kind of oil. The values for other kinds are quite likely to vary considerably from those shown by this curve, but the manner in which the changes occur are much the same.

It should be explained that the solid part of the curve was plotted from actual test values, also the beginning and end of the dotted portion. The path followed by the dotted part indicates what may be expected to occur during the first part of the cycle. (As no refrigerating machine was available, it was necessary to make the tests last winter, and but a limited number of points could be obtained.)

Effect of Moisture

Oil, as far as dielectric strength is concerned is extremely sensitive to moisture. As already stated, even the slightest amount is detrimental. It is therefore, of the greatest importance not only to remove every trace before putting the oil into service, but also to maintain this condition of dryness under continued operation.

The accompanying curves, Figs. 8 and 9, still further emphasize these facts, indicating, as they do, the reduction in dielectric strength for gradually increasing percentages of moisture. The first was plotted from results of tests on a medium grade and the second from tests on a light grade oil.

It is often difficult to determine how moisture can be taken up by oil contained in apparatus having fairly tight covers, yet this frequently happens, nevertheless. Some of the moisture may settle to the bottom, where it can be gotten rid of by simply drawing off a limited quantity of oil. A certain percentage on the other hand, will be retained and kept in circulation. The percentage which may be safely allowed naturally depends to some extent on the voltage of the apparatus, but that this amount must be extremely small is apparent from the curves just mentioned. Even 3/100 of one per cent, reduces the dielectric strength to three-quarters. (This means but five or six drops of water per quart of oil.) With the addition of 1/100 of one per cent of moisture, the strength is reduced to one-half.

It is evident from the above that the importance of dry oil cannot be over estimated. The apparatus into which it is to be

placed, including the interior surface of the tanks, should be thoroughly dried, and not only should the oil be tested for dielectric strength before it is put into service, but at stated periods afterwards, as well. Oil found below the desired value should be dried or replaced with new.

As to the various methods which have been used for detecting moisture, the following may be mentioned:

A quantity of oil may be placed in a tank and allowed to settle for a week or ten days, at the end of which time a sample may be taken from the bottom with a glass tube, or a thief. If much water is present, the eye will readily detect it.

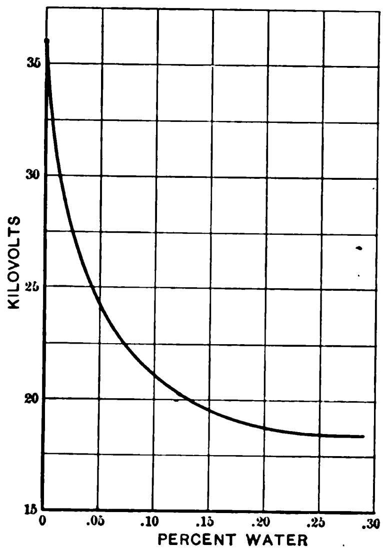


FIG. 8—Influence of moisture on dielectric strength of oil of medium viscosity

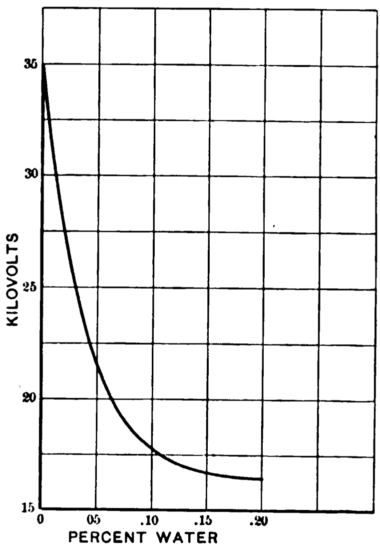


FIG. 9—Influence of moisture on dielectric strength of light oil

A piece of cold glass plate may be held over a sample and the latter heated to the boiling point of water. Any moisture driven off will be condensed on the plate.

Anhydrous copper sulphate is sometimes used, a small quantity being shaken with the oil to be tested. If it contains moisture in any considerable quantity, a slightly blueish color will result.

Still another method is to thrust a red hot nail or piece of wire into a sample of oil. A crackling noise will be heard if moisture is present. If dry, there will simply be a puff of smoke.

A similar test can be made by placing a sample of oil in a

small porcelain dish, and heating it over a flame. If moisture is present a sharp crackling noise will result, much the same as with the hot nail or wire just referred to.

Of all the methods which have been used, however, the dielectric strength test is the most satisfactory and reliable. Moreover, it is extremely sensitive so that even the smallest percentage of moisture may be detected.

This last method is the only one which can be recommended as being absolutely sure. The one mentioned just before this, *i. e.*, heating the oil in a porcelain dish is the next most reliable, but even this is not certain. (A number of tests were made on various samples to determine the accuracy of this method, and not more than 60 per cent of the results were correct. It may be of value, occasionally, however, when no high voltage testing outfit is available). The hot wire method would come in the same class.

The other tests mentioned are only of service when large quantities of moisture are present. Otherwise, they are not reliable.

Methods of Drying and Filtering Oil

In view of the importance of dry oil, many methods for removing moisture have been devised. Some of these are suitable for laboratory only, and are not practical for commercial purposes. Others are quite satisfactory for use in the shop and testing department, but on account of the expensive apparatus required, cannot well be employed for installation work or in connection with any but the largest power plants. Still other methods have been tried out and then laid aside, either on account of cost of operation or length of time required for treatment. As a result, there are but few methods which are of much service commercially. It may be well, however, to mention all, some briefly, others at greater length, depending upon their importance. The following will be considered.

Drying by means of:

(1) Chemicals,
(2) Heat,
(3) Heat and vacuum,
(4) Heat and air,
(5) Settling,
(6) Centrifugal separators,
(7) Paper filters,
(8) Miscellaneous.

It should be noted here that the first five methods mentioned above, are suitable only for removing moisture, and do not remove dirt or other foreign matter. The next two in the list purify as well as dry. Sometimes one method, sometimes a combination of several methods have been used successfully.

Chemicals. Of the various chemicals used for dehydrating oil, calcium chloride has given the most satisfactory results, although calcium oxide, (unslacked lime) is also used extensively and gives good results. Calcium carbide and metallic sodium, as well as other agents have been tried with varying degrees of success.

The accompanying curves, Fig. 10, indicate the comparative

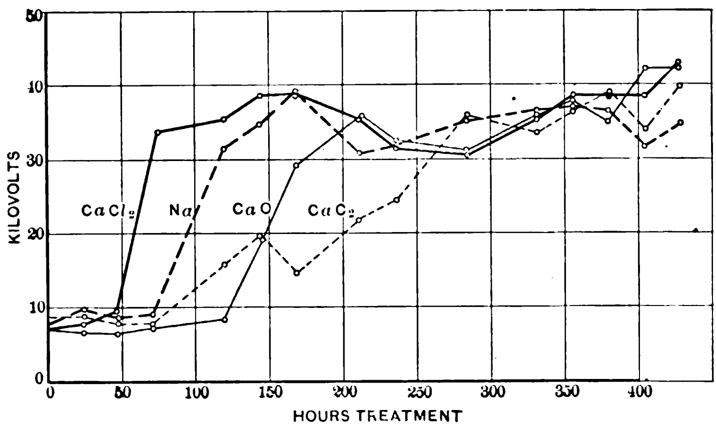


FIG. 10—Effectiveness of oil drying material
Calcium chloride, $CaCl_2$; Metallic sodium, Na; Unslaked lime, CaO; Calcium carbide, CaC_2

rates at which these materials remove moisture from oil. It will be noted that calcium chloride required seventy hours; metallic sodium 115; calcium oxide 165; and calcium carbide 260 hours, to bring the oil from a dielectric strength of 7,000 volts up to 30,000. (Tests made between ½-in. disks placed 2/10-in. apart.)

The tests were made first by mixing a small amount of water with a quantity of oil, separating into four parts and adding respectively the four drying agents; six per cent by weight in each case. The drying materials were chemically pure, and in order to expose the same surface to the oil, they were broken up into about ¼-in. lumps. The samples were thoroughly shaken and allowed to stand 24 hours after which they were tested.

The process of shaking, allowing to stand, testing, etc., was repeated every 24 hours, until the oil had returned to its initial dielectric strength.

Calcium chloride required the least time of all.

Metallic sodium came next in order of time. Its use, however, is considered dangerous, inasmuch as it unites with water to form hydrogen and caustic soda, and if a large quantity of water is present the reaction might cause sufficient heat to ignite the hydrogen. Moreover, the caustic soda formed dissolves in oil and tends to soften insulating materials, such as varnish or gum compounds.

Calcium oxide required still longer time to absorb the moisture as was also the case with calcium carbide. The latter also has the disadvantage that it gives off a highly inflammable gas, acetylene, when it comes in contact with water.

Continuing the subject of calcium chloride as a dryer, it may be of interest to mention the results of several tests made to determine the best method of utilizing such material for removing moisture from oil in transformer tanks, when the natural circulation of the oil alone is relied upon for bringing all portions in contact with the calcium.

Three tests were made, the oil in each instance being placed in a fairly large sized tank, and maintained at a temperature of about 80 deg. cent. by means of a wire-coil rheostat at the bottom. One per cent of water was added to the oil and thoroughly mixed with it for each of the three trials. In the first trial no calcium chloride was used, the test being made to determine the length of time required to bring the oil back to a given dielectric strength by settling only. In the second trial, a quantity of calcium chloride was placed at the bottom of the tank, and for the third trial the chloride was placed in a perforated metal tube, suspended in the tank midway between the top and the bottom.

At the beginning of each trial, the oil measured approximately 7,000 volts, (tested between ½-in. disks, placed 2/10-in. apart.) The runs were continued until the oil at the top of the tank reached a strength of 50,000 volts, (that at the middle measured 45,000 volts, or over.) Ten days were required in the first instance, four in the second and two in the third. The most effective method used therefore, was that in which the chloride was suspended in the center of the tank. Whenever this method is used, however, care must be taken to provide a suitable recep-

tacle for collecting the water and wet chloride, and yet allow free contact between the fresh chloride and the oil.

A method which gives still better results as regard time required, is one which provides for the forcing of oil through a receptacle containing calcium chloride or calcium oxide, (unslacked lime.) The quantity of oil which can be dried per hour is thus greatly increased. It is usual in connection with this treatment, to complete the process by forcing the oil through dry sand. This removes all traces of dirt and foreign material and prevents any particles of lime which may be held in suspension, from passing through into the receiving reservoir. Bone black or Fuller's earth are sometimes used in connection with this process, in case it is desired to remove coloring matter from the oil as well as other impurities.*

Heat. Heat is frequently employed for removing moisture. It is sometimes applied to the outside of the receptacle containing the oil, and in other cases is introduced by means of steam coils or an electric heater. The last mentioned arrangement is preferable, and is usually more convenient. In all cases the temperature maintained is about 105 deg., or, in other words, slightly above the boiling point of water.

This process at best is slow. It must be watched with great care, and there is always the danger of injuring the oil from over-heating. Long continued overheating will cause a deposit to be thrown down and is also liable to change the nature of the oil by driving off some of the lighter hydrocarbons.

Heat and Vacuum. The danger of the overheating mentioned above may be practically overcome by removing the air pressure from the drying receptacle and employing heat as before. The reason for this is that water boils at much lower temperature in vacuum than ordinary air pressure. Thus, in a 27-in. vacuum, boiling occurs at 46 deg.; in a 28-in. vacuum at 38 deg., and in a 29-in vacuum at 25 deg. cent., etc.

This process may be still further facilitated by allowing dry air to bubble slowly through the oil. The air may be readily freed from moisture by first passing it through some dehydrating substance, such as calcium chloride or unslacked lime.

Heat and Air. Perfectly dry air has also been used to advantage. This may be forced through numerous openings at the bottom of the tank and allowed to bubble up to the surface.

* Article by S. M. Kintner, "The Treating of Transformer Oil," *Electric Journal*, October, 1906.

The oil in the containing tank may, or may not, be heated, although heating naturally facilitates the operation. The air may be dried by passing it through calcium chloride or other drying agents.

Instead of using air alone, the air and vacuum process may be employed, as outlined at the end of the preceding paragraph.

Settling. When oil contains a large quantity of water it may be gotten rid of almost entirely by allowing it to stand for some time undisturbed. The water as well as some of the impurities gradually settle to the bottom, leaving a dry oil to be drawn off from the top. The process usually requires a number of days, and herein lies the greatest difficulty in its use.

Centrifugal Separation. The different specific gravities of oil and water make it possible to separate the two by centrifugal action. It is extremely difficult to remove all of the moisture by this means, but it serves a good purpose in taking out a considerable portion of it when the oil is extremely damp. The remainder, however, may be removed by means of a filter within the upper part of the machine, so that virtually both steps in the process take place at the same time. The operation may be accomplished by a standard cream separator like the De Laval. The damp oil is fed into the top and passes down into the center of the rapidly revolving element. The centrifugal action forces the water, which is the heavier of the two, toward the outer casing, where it may be drawn off like skim milk. The oil, like the cream, passes into a central chamber and then up through sheets of filtering material into a receiving reservoir, from which it may be drawn off for use. During the first part of the operation, all but about one-tenth of one per cent of moisture may be removed, while the small amount remaining, is taken out by the filter.

Damp oil has in this way been raised in dielectric strength to a value of between 40,000 and 45,000 volts, (measured between ½-in. discs, placed 2/10-in. apart.)

With a medium sized machine it is possible to dry and clarify from 50 to 60 gallons per hour, provided the oil is not in too poor condition to start with.

Paper Filters. It has been known for some time that ordinary filter paper, such as is used in chemical laboratories will allow oil to pass slowly through it, but will not allow water to pass. This principle has recently been employed on a larger scale in what is known as an oil dryer and purifier. This piece of ap-

paratus consists of a press for holding the paper, a pressure pump and an operating motor, together with necessary piping, valves, gauges, etc.

The most interesting part of the outfit is made up of a number of alternate grids, and chambers arranged in such a way that square sheets of blotting paper may be placed between them and the entire device bolted together. By means of suitable channels the oil from the pressure pump is led into the chambers, forced through the blotting paper and finally discharged into the receiving tank. The blotting paper allows the oil to pass, but retains all moisture and impurities thus raising the dielectric strength to values as high as 60,000 to 70,000 volts, (measured between ½-in. disks, placed 2/10-in. apart.)

With a moderate sized press, 600 gallons of medium grade

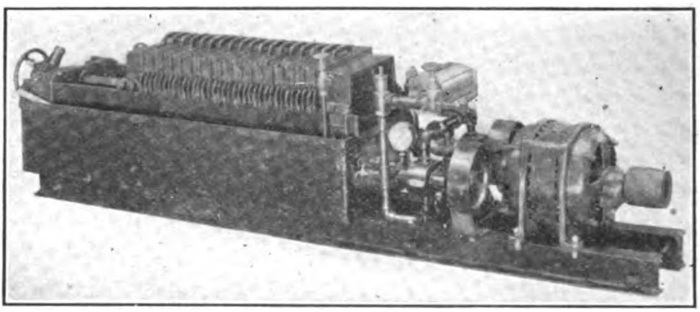


FIG. 11—Oil drier and purifier

oil may be treated per hour, and twice this amount of light oil, it merely being necessary to replace the blotting paper occasionally, once every half-hour to an hour is sufficient with oil in fair condition.

Not only can such an outfit be used for first drying and purifying oil before it is introduced into high voltage transformers, but it may also be employed from time to time while the transformers are in operation. In such cases the oil is taken from the bottom of the transformer tank, forced through the filter press and back into the transformer at the top of the tank, this process, of course, being continued until the oil reaches the desired dielectric strength.

The general construction of the outfit is shown in Fig. 11.

Miscellaneous Methods. Capillary action has been made use

of to some extent in freeing moisture from oil, also electrostatic force. Sponges have been tried and found to give fairly good results. The expense however is prohibitive, as only the very best grade of sponges are at all suitable. For removing impurities sand gives excellent results. Cheesecloth is also frequently used.

Presence of Sulphur and Paraffine

While the presence of free sulphur has an effect on the dielectric strength of oil, the greatest danger lies in the fact that even in minute quantities it vigorously attacks the copper.

In time, conductors have been known to be completely severed on account of sulphur alone. It may be detected very readily by dipping a small polished wire into the oil, which has previously been heated, and allowing it to remain until it becomes black. The time required for this to occur may be judged from the following table, which is made up from results of tests on oil heated to 85 deg. cent.

Per cent sulphur	Time required to blacken copper wire
1/10 of 1 per cent	2 to 3 minutes
1/100 of 1 per cent	30 minutes
1/1000 of 1 per cent	15 to 20 hours
1/10000 of 1 per cent	Uncertain

In some oils small amounts of sulphur exist in very strong chemical combination. These however, have not been proved to be deleterious, probably because the combination is so strong that it is difficult to break it up.

As to paraffine, there must be freedom from solid material of this kind in solution; otherwise, particularly in water-cooled apparatus, it might be frozen out of solution and result in clogging of the oil ducts.

Insulation Resistance as an Indication of Dielectric Strength

It has sometimes been thought that insulation resistance of oil is an indication of its dielectric strength. The accompanying curve Fig. 12 will show that this is by no means always the case, unless temperature is also taken into consideration. It indicates what is experienced every day in heating transformers. With increase in temperature the insulation resistance falls

very rapidly, while the dielectric strength of the oil gradually increases until conditions become constant.

If moisture is present, in a transformer, for example, the insulation resistance may drop to a very low value when the oil is heated, and then rise for a time as the last traces of moisture are driven off.

It is only safe to assume that everything is dry when the insulation resistance becomes constant and remains so for several hours. Even this final value, though, may be far below that obtained when the oil was cold.

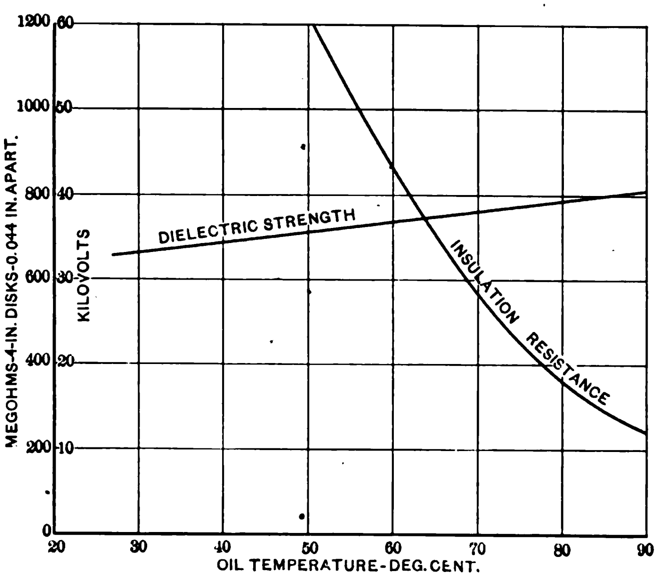


FIG. 12—Variation of dielectric strength and insulation resistance with temperature

SUMMARY

Having first laid down the conditions which an insulating material must fulfil in order to give satisfactory results, we have shown that oil best meets these provided it is used within definite limits. The limits have been found only after making a careful study of the more important characteristics, and it has only been by a systematic investigation of the chemical and physical properties that oil has gradually been made to attain its present state of superiority. It fulfils the ideal conditions so

well that it is almost universally used in spite of the fact that it requires unusual care in its treatment and handling.

It is hoped that the paper will aid in giving a clearer understanding of the various properties, not only that such treatment and handling may be made comparatively simple, but also to assist in the selection of oil and its use.

In closing, the writer wishes to acknowledge the valuable assistance received from Dr. C. P. Steinmetz, Mr. A. B. Hendricks, Jr., and Mr. J. A. Capp, all of whom have taken an active interest in the tests, experimental work and study of the results.

NOTE

The following paper is to be read at the 27th annual convention of the American Institute of Electrical Engineers in **Jefferson, N.H., June 28—July 1, 1910.** This paper is to be presented under the auspices of the Electric Lighting Committee of the Institute. All those connected with the Institute and desiring to take part in the discussion of this paper may do so by being present at the meeting; or, if this is not possible, by sending in a written contribution.

Written contributions will be read at the meeting, time permitting, for which they are intended, either in full, in abstract, or as a part of a general statement giving a summary of the views of those taking the same position in the matter.

The principal object in getting out the paper in advance of the meeting is to enable and encourage those not in a position to attend the meetings to take part in the discussion by mail.

Contributions to the discussion of this paper should be mailed to **William L. Robb, Chairman Electric Lighting Committee, P. O. Box 532, Troy, N. Y.,** so that they will be received not later than June 23, 1910. Written contributions arriving within 30 days thereafter will be treated as if presented at the meeting.

(Rosa)

A paper to be presented at the 27th Annual Convention of the American Institute of Electrical Engineers, Jefferson, N. H., June 28–July 1, 1910.

CARBON FILAMENT LAMPS AS PHOTOMETRIC STANDARDS

BY E. B. ROSA AND G. W. MIDDLEKAUFF

The primary standards employed in physical measurements are of two kinds; (1) those which can be described in such terms that they can be accurately verified or reproduced from their specifications, and (2) those which are more or less arbitrary, and which cannot be accurately reproduced except by copying other standards of the same kind. The international ohm is a standard of the first kind, as it is specified in terms of the resistance of a definite column of mercury at a certain temperature, and it can be reproduced without reference to any other standard of resistance. The meter was originally intended to be such a standard, being defined in terms of the dimensions of the earth. But when it was found that the dimensions of the earth were different from what had been supposed and that the meter would require a new definition, the reference to the earth was abandoned and the meter became a standard of the second kind, only to be reproduced by reference to other meter bars, of which there were a sufficient number in existence to make it possible to maintain the meter indefinitely in this way. More recently the meter has been expressed in terms of the wave length of light so exactly that it could be reproduced accurately if all length standards were lost. Hence the meter has again become a primary standard of the first kind. However, meter bars are so permanent that in practice they are verified and reproduced by comparing with one another, without reference to the absolute specification in terms of the wave length of light.

The kilogram was intended to be a natural unit, so defined in terms of the unit of length and the density of water as to be

a standard of the first kind. But owing to the difficulty of deriving it in this way it is more accurate as well as more convenient to regard it as a standard of the second kind, and to verify and reproduce standards of mass by reference to well made platinum standards, without attempting to derive it according to its original definition.

Thermometers are standards of the first kind, inasmuch as they are referred to the natural interval between the freezing and boiling points of water under standard conditions, and they can therefore be verified or reproduced by referring to the formal specifications.

The unit quantity of electricity, the international coulomb, is defined in terms of the quantity of silver it will deposit under standard condition when passed through a solution of nitrate of silver. It is therefore a primary standard of the first kind.

Primary photometric standards may be of the first kind or of the second kind. Although primary standards of the first kind are to be preferred, *other things being equal*, obviously a reliable, convenient and permanent standard of the second kind is better than an unreliable, inconvenient and ephemeral standard of the first kind. Many primary photometric standards of the first kind have been proposed and a considerable number have been used. The sperm candle is made to carefully stated specifications, and has been more widely used than any other photometric standard. But it is a very crude standard. The carcel lamp in France, the Harcourt pentane lamp in England and the Hefner lamp in Germany are accepted as primary photometric standards of the first kind in the respective countries. They are made and used according to very elaborate specifications, but as the light is the result of the specified fuel burning in a specified lamp surrounded by a specified atmosphere the standard is not merely the lamp, but the combination of lamp, fuel and atmosphere, the two latter of which are constantly changing. The standard is therefore not permanent but ephemeral, and the greatest difficulty in the use of flame standards is not the lamp, which is only the instrument in which combustion takes place. The greatest difficulty is to secure uniform fuel and uniform atmospheric conditions, and as considerable fluctuations in both are inevitable, one is driven to taking many observations and averaging out the errors as far as possible by taking the mean. For use in ordinary gas photometry, flame standards are convenient. But for precision photometry in general or for

determining and maintaining a photometric unit, it is not unfair to say that flame standards are not as convenient or reliable as primary standards ought to be.

The radiation from incandescent platinum, at its melting point, was long ago proposed by Violle as a primary photometric unit of the first kind. But although enormous progress has been made in obtaining and maintaining and measuring high temperatures, and several serious attempts have been made to make Violle's proposal practicable, nobody has ever succeeded in doing as well with it as can be done with flame standards. Steinmetz has recently made a new proposal for a primary photometric standard of the first kind, but the realization of this proposal to the extent of obtaining a standard of precision seems very difficult if not altogether impossible.

The most successful photometric standards of the second kind are carbon-filament incandescent lamps, which have been employed for many years as convenient working standards, and in recent years have been employed in making careful comparisons of the photometric standards of different countries. Such lamps cannot of course be made accurately to specifications, but if they are sufficiently permanent they may be employed to maintain the unit of light for an indefinite period. Probably nothing is more permanent than pure carbon, sealed in a vacuum and kept at ordinary (room) temperatures. Hence, if carbon filament lamps can be prepared which will not change appreciably when burned say 100 hours under working conditions, there is reason to believe that they will remain constant for a long period of years, (barring accidents) and that a group of such lamps will afford a means of maintaining the unit of light constant for a long time. How long and how accurately can of course be determined only by experience. It is the purpose of this paper to give an account of work done at the Bureau of Standards which tends to show that carbon filament lamps when properly made and carefully seasoned are remarkably permanent and reliable, and that a single group of lamps might serve to maintain the unit of light for a century, if we supposed them protected from violence and used with ordinary care as primary reference standards, even though burned as much as half an hour at a time every six months for the entire hundred years. Before describing our recent work, however, we shall refer to the comparison of the photometric units of different countries made by means of incandescent lamps in recent years.

In 1907 Hyde[1] published an account of comparisons that had been made the preceding year, of the units of luminous intensity of the Bureau of Standards with those of the Reichsanstalt, the National Physical Laboratory and the Laboratoire Central d'Electricité, using incandescent lamps. Six sets of measurements are given on twelve lamps, six of which were rotating and six stationary, and the mean of the six measurements (two at the Bureau of Standards, two at the National Physical Laboratory, and one each at the other two laboratories) was taken as giving the true relative values of the lamps. The average deviation from the mean of the separate values was only two parts in a thousand for the stationary lamps and three parts in a thousand for the rotating. The unit of the Bureau was found to have very closely the same value as compared with the Reichsanstalt as it had four years before.

In 1908 one of the present authors carried a number of standard lamps of the Bureau to Europe both in the early spring and again in the autumn for further comparisons with the standards of the above named institutions. The Bureau unit was found by the comparison of 1906 and the two comparisons of 1908 to be 1.6 per cent larger than that of the National Physical Laboratory, and the latter was in substantial agreement, within the errors of the comparisons, with the unit of the Laboratoire Central. With so close agreement in three successive comparisons with carbon filament lamps, there seemed every reason to believe that a common photometric unit could be maintained in the same way if once the several countries came together. In order to facilitate the agreement and at the same time to bring the Bureau unit nearer to that of the gas industry of America, the Bureau of Standards on July 1, 1909, reduced its unit by 1.6 per cent and at the same time announced the agreement that had been entered into between the national standardizing laboratories of America, England and France to maintain their common unit of candle-power as accurately constant as possible by periodic intercomparisons of their standards in the future. This agreement, which gives a common photometric unit to so large a part of the world, inasmuch as the same unit, which it has been proposed to call the International Candle, is used in many other countries, could not have been reached at this time if it had not been for the excellent service which carbon filament lamps have given as primary photometric standards.

1. Bulletin, Bureau of Standards, Vol. 3, p. 65, Reprint No. 50.

In 1909, after the agreement concerning the common unit of candle-power had been effected, a dozen lamps were sent to the National Physical Laboratory for further comparison, and after careful measurement there they were returned and re-measured here. Two of the lamps showed slight but appreciable changes, which somewhat marred the comparison. These lamps, unlike our primary standards which had been used in the comparisons of 1906 and 1908 had not been seasoned at the Bureau, but were purchased seasoned and were supposed to be lamps of excellent quality. This incident emphasized the importance of knowing the previous history of a lamp used as a photometric standard, not only as to its candle-power at given voltage but as to the resistance of the filament. It was decided in the future to use no lamps not seasoned at the Bureau and to keep a very careful record of the life history of every lamp to be used as a primary standard, or a traveling comparison lamp.

Believing that carbon filament incandescent lamps could be prepared and measured so that appreciably better performance could be secured than had been done in the past, even though the recent comparison with foreign laboratories had been very satisfactory; and to see to what extent variations would be due to changes in the lamps, we determined to increase the precision of measurement and to study very carefully the performance of the lamps during the seasoning process and also during a subsequent burning which would correspond to a long useful life of the lamp as a standard.

To increase the accuracy of the photometric measurements we put up a double photometer, consisting of two standard photometers of the Reichsanstalt pattern with Lummer-Brodhun photometer heads, as made by Schmidt & Haensch, placed end to end, as shown in Fig. 1. The measurements being made by substitution, the standards and the lamps to be compared with them are placed successively in the socket of the rotator at the middle of the double photometer. The comparison lamps, each linked to the corresponding photometer carriage are near the ends of the photometer bench. These lamps are connected in parallel, and their common voltage maintained constant by means of regulating rheostats, a potentiometer constantly indicating any slight deviation in voltage. The current comes from a large storage battery carrying no other load, which permits the voltage to be regulated very closely. The potentiometer has a sensibility of 0.001 volt when using 100 volts, and

variations during the measurements are seldom greater than a few thousandths.

A second potentiometer measures the voltage on the standard lamp or lamps to be compared with the standard, and of course gives the voltage with the same precision as that given by the first potentiometer. The current flowing in the lamp under test is measured by the first potentiometer, connections being quickly changed so that current and voltage measurements succeed one another rapidly. Thus the voltage and current of the standard lamps and of the lamps to be compared with them are measured simultaneously, the light reflected from the two galvanometers falling on the same scale, so that a single operator

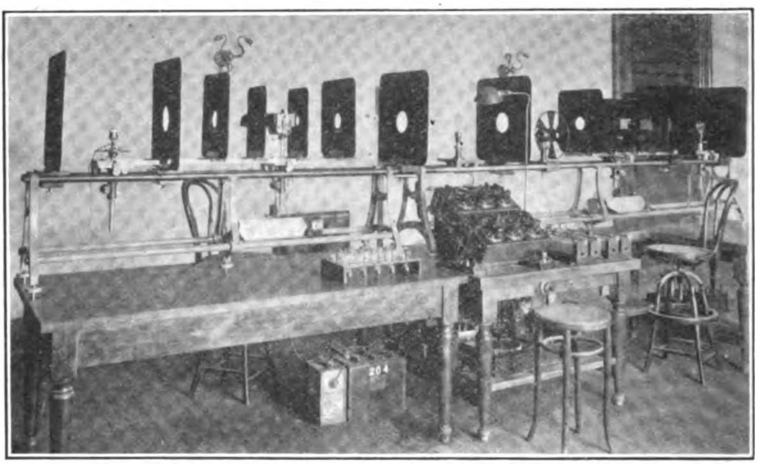


FIG. 1—Double photometer

can manage both instruments conveniently. The current is recorded to the fifth decimal place, and is accurate to two or three units in the last place. If the current is constant at constant voltage, when measured to this precision, it indicates that the resistance of the filament is satisfactorily constant. If, on the other hand, the lamps have not been seasoned properly and the resistance is decreasing or increasing as they burn, as often happens with lamps sent to the Bureau for standardization, this may be detected in 10 minutes or less without measuring the light. Indeed, no lamp should be measured as a standard if its resistance while burning does not remain constant under a short test of this kind.

This method of testing lamps has been in use at the Bureau for more than a year, and was reported to the Physical Society at its meeting here in April 1909.

It will be evident that the purpose of using potentiometers of highest precision is not because it is necessary to have so high precision in making the photometric measurements, but rather as affording valuable information in a short time as to the condition of the filaments, and of determining whether any change in a filament has occurred since its previous measurement.

Stationary lamps are of course measured in the same holder, with the rotator at rest.

The advantages of the double photometer are, (1) that three men can make as many measurements per hour as two men could do in two hours; (2) the standards as well as the lamps to be measured require to be burned only half as long for a given number of measurements; (3) there is a valuable check of one observer against the other when two men are measuring a given light source at the same time.

In the case of lamps measured stationary, one-half of the measurements are made with the lamp in one position and the other half when rotated through 180 deg. This eliminates any difference in the measurements of each observer due to lack of centering of the filament.

The Method of Recording. Until recently the observer at the photometer read the graduated bar and recorded each setting before taking the next. To accelerate the work, and at the same time to increase the accuracy, recording cylinders have been provided on all the precision photometers, Fig. 2, so that the reading is represented by a dot on a record sheet wrapped on the cylinder, made by means of an electromagnet and a type ribbon. The observer presses a key when the setting is made, and proceeds at once to a new setting. This saves two thirds of the time required when settings are read and recorded, and eliminates the errors which sometimes occur in the observations of reading and recording. It also eliminates the labor and possible arithmetical errors due to finding the mean of a lot of individual readings, and gives a printed original record which is filed and can be consulted at any time. This method not only saves a large amount of time, permitting at least three times as many observations to be taken and evaluated in a given time, but it makes the observers freer from prejudice in reading,

and as already stated, eliminates many possibilities of error both in recording and computing.

The cylinders are connected to a geared mechanism so that the record sheet advances half a millimeter after each setting is printed. This prevents two points falling on one another, and shows on the record the order in which the readings were taken.

The Direct Reading Scale. A diagonal scale is printed on the record sheet to permit reading of candle-power directly from the scale, in terms of one or more standard lamps which have been

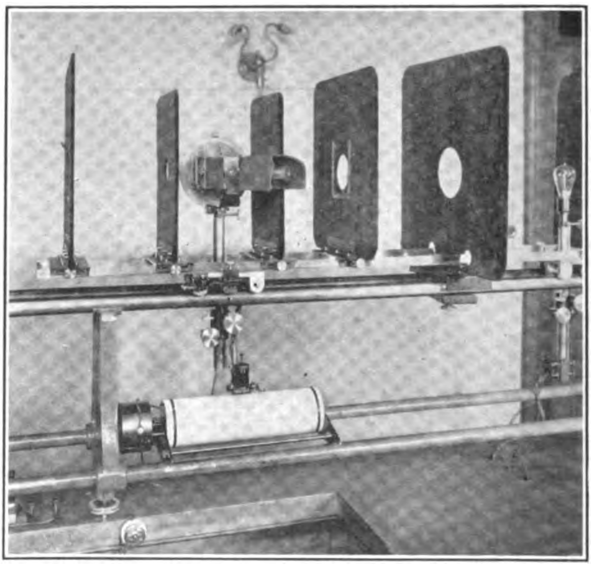


FIG. 2—Precision photometer

measured in the comparisons, without any computations. This will be fully described in the near future by one of the present authors in a separate article.[2] The accompanying photograph, Fig. 3, shows the scale as printed on the record sheet, together with the candle-power of a large number of lamps that were recorded in one series of observations. Ordinarily, since the candle-powers are proportional to the squares of the distances from the lamps to the photometer, (the comparison lamp being at constant distance), it is necessary to get the ratios of the squares

2. See abstract in *Phys. Review*, of paper given at April, 1910, meeting of Physical Society, by G. W. Middlekauff.

of the distances of the standards and of the lamps to be measured, and multiply the ratio of the squares by the candle-power of the standard. It is to eliminate all the numerical work of getting

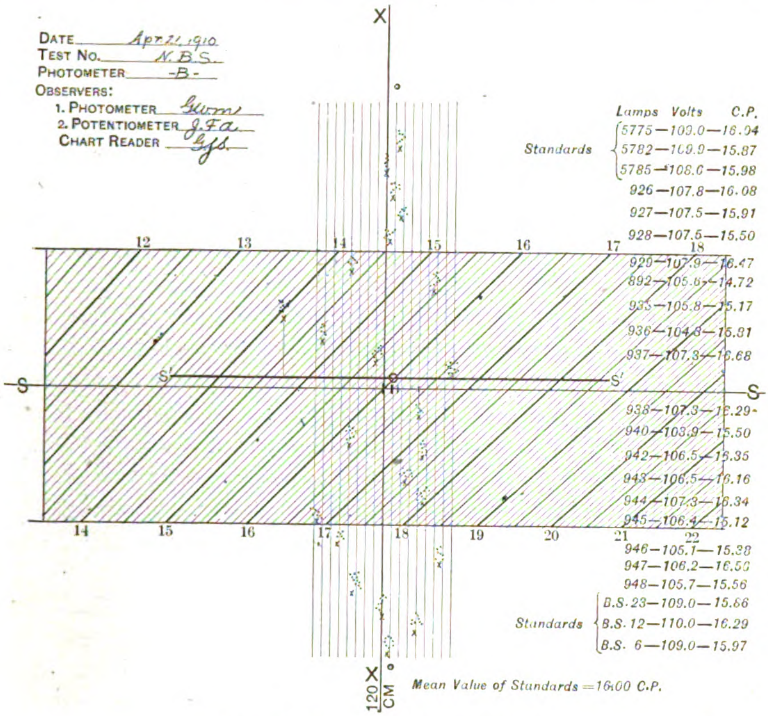


FIG. 3—Complete record sheet

This is a reproduction of a completed sheet, or chart, of a run made on a set of six standards, and seventeen of the lamps, herein described, compared with them. The numbers of the lamps, their voltages, and their candle-power, as read from the scale are written along the margin, each lamp being recorded opposite its corresponding group of record dots. The proper position of the scale S′S′, from which the candle-power values were read, was determined in the following manner. Preliminary *relative* candle-power readings of the six standards, whose mean value was known to be 16.00 candle-power, were made from the standard scale, SS, and each reading was recorded by a mark on the scale, as shown. Through the mean of these six readings, which was found to be 16.10 candle-power, the line 00 was drawn perpendicular to SS, and through the point on 00 where the reading is exactly 16.00 candle-power (the mean value of the standards), the desired scale S′S′ was drawn parallel to the standard scale SS. All values, including those of the standards, were then read from this scale and recorded. The individual values of the standards in the order recorded were 16.00, 15.90, 15.98, 15.82, 16.33 and 15.96 candle-power, respectively. A comparison of these values with those read from the scale and recorded on the chart above gives a fair indication of the accuracy of the measurements.

these squares, their ratio, and the product of the ratio into the candle-power of the standard, that this scale has been devised, the candle-power of the lamps which have been measured being

read off directly, and with equal facility whether they are referred to a single standard or to the mean of several standards. This scale thus saves a very large amount of time, and further facilitates the work of studying the performance of lamps intended for standards, and of comparing with the highest precision different groups of lamps that have been selected as standards.

Carbon-filament incandescent lamps are usually operated as standards at a constant voltage, the current being measured as a check. Sometimes they have been measured at constant current, the voltage being varied slightly if necessary. If the lamps have constant resistance, of course, these two methods would amount to the same thing. But as carbon-filament lamps do not have constant resistance, but generally show a decreasing resistance followed after a longer or shorter period by an increasing resistance, it becomes a matter of prime importance whether the best performance can be secured by operating lamps regularly during their useful life as standards at constant voltage or constant current, or whether still better results can be obtained by operating them at constant watts. Obviously, if the radiation from the surface of the filament is unchanged and the bulb does not blacken or change its absorption, the most constant candle-power will be secured by operating the lamp at constant watts; a constant rate of energy supply and a constant conversion factor giving a constant flux of light. But whether the radiation from the filament and the absorption in the bulb will be constant at constant watts could be determined only by experiment.

A number of lamps were therefore taken and the light measured at constant watts, correcting the light to what it would have been at constant voltage and constant current.[3] This correction was verified by direct measurements. A considerable number of lamps were so studied, the measurements being made with great care, and the lamps burned between measurements until they had burned 150 or 200 hours. One such life curve is given in Fig. 4, curve A, which shows the three candle power curves, at (1) constant voltage, (2) constant current and (3) constant watts, the curve below giving the current at constant voltage. The candle power at constant voltage first increases and then decreases steadily, falling 0.25 candle-power in 100 hours,

3. This work was done more than a year ago, and the results reported to the Physical Society in April, 1909.

from 15 to 115 hours in the life curve. At constant current the candle-power first drops rapidly, but after 15 hours it drops very slowly for 50 hours and slowly rises for the last 100 hours. The voltage of course is rising during this period, so that the watts are increasing. The third curve, at constant watts, decreases steadily from the start.

The curves B of Fig. 4 show the performance of another lamp starting from the beginning of its period of seasoning. The

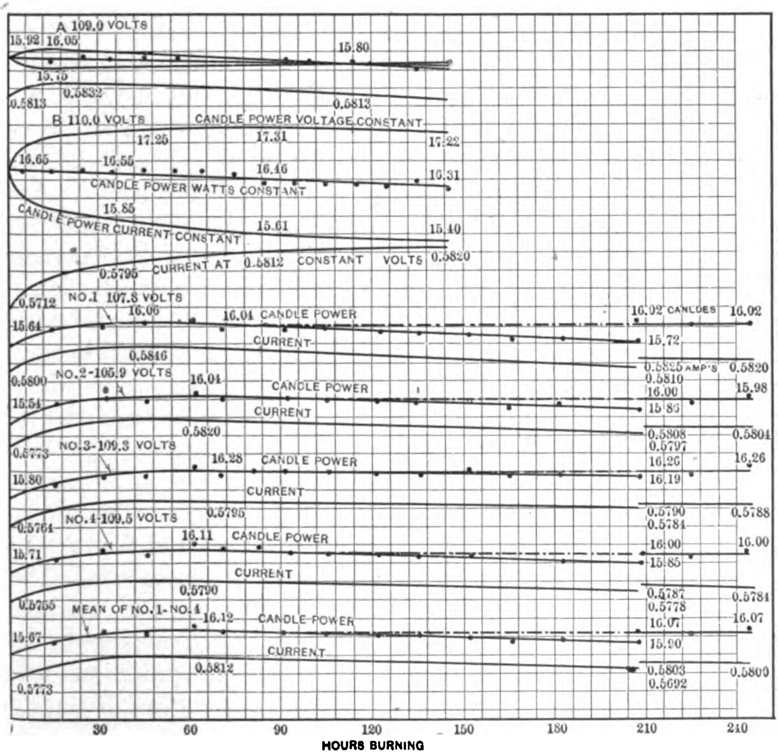


FIG. 4

candle-power at constant voltage rises from 16.60 to 17.25 in 40 hours, and during the next 100 hours it rises about 0.06 candle and falls to 0.03 below its value at 40 hours of burning.

This would be considered a good performance for a standard lamp. But at constant current it drops off in candle-power quite appreciably, and even at constant watts very considerably. There is evidently an increasing loss of light during the entire period, and the candle-power holds up so well on the constant

voltage curve only because the current and therefore the energy is constantly increasing. Obviously such a lamp is not an ideal standard, for there is no guaranty that this increasing loss of light would be equal in any two lamps.

It was suspected that this loss of light was due to blackening of the bulbs, and on burning further the blackening became evident. The lamps had been purchased to use as standards several years previously, and were used for these experiments under the impression that they were very good lamps. Although these lamps showed their best performance at constant voltage, we were still uncertain how to operate any other lot of lamps as standards to give the best result. We believed that the highest grade of lamps in larger bulbs than usual would show so small a blackening that to operate them at constant watts, the theoretically best way, would give the best results. Accordingly we asked a lamp manufacturer to make us 200 64-watt, 16-c-p. 110-volt lamps, using 32-c-p. bulbs, and to prepare them with more than usual care. The bases were nickel plated to remain bright for a long period and to readily distinguish them from other lamps. The lamps were prepared with the idea of studying their performance carefully under the three conditions above stated, of ascertaining which would give the best results, and of selecting the best lamps for primary standards.

One hundred lamps in two lots of 50 each were seasoned by burning at approximately 3.5 watts per c-p. The lamps of the first lot were measured at the beginning and at every 10 or 15 hours of burning, and the results plotted in curves. The candle-power was measured at 4 watts per c-p., the voltages being so chosen as to give a close color match with our standards. Six carefully rated lamps were used as working standards in this work, the lamps being measured in terms of the mean of the six taken as constant. Five of the above lamps were taken at random and burned 208 hours, at constant voltage, in order to ascertain how well they would hold up their candle-power. It was found that the candle-power curve dropped steadily in each of four lamps, after the initial rise during the 50 hours of seasoning. That is to say, the maximum candle-power was attained after about fifty or sixty hours burning and then slowly decreased. (One lamp was discarded as it was abnormal, having first decreased and then increased in candle-power, at constant voltage).

At 208 hours, the mean candle-power of the four had decreased from 16.12 to 15.90, or a little more than one per cent. The

current had decreased steadily from 0.5812 to 0.5792 amperes. It was thus evident that the decrease in candle-power was due to the increase of resistance of the filament. Calculating what the candle-power would have been if the voltage had been increased to keep the *watts* constant, we found the average drop at constant watts was only from 16.12 to 16.07 c-p.

Additional measurements were then made at constant watts, and the lamp burned further to 250 hours. The candle-power as corrected is indicated in the dotted lines of Fig. 4. The candle-power was measured between 208 and 250 hours at constant watts the current decreasing from 0.5803 to 0.5800 ampere, average of the four lamps. It is evident that these lamps did much better at constant watts than they would have done either at constant voltage or constant current.

A decrease in candle-power of only 0.05 in 200 hours of burning after seasoning was very satisfactory, and we proceeded to season and measure the remaining lamps. Out of 95 lamps, 36 were selected after from 75 to 100 hours of burning as exceptionally good standards. These lamps showed practically no change in resistance for 30 to 50 hours of burning, after seasoning (that is, the current was constant at constant voltage) and the light was constant.

About 50 lamps more showed constant candle-power at constant watts, in some cases the voltage being increased and in other cases reduced to maintain the watts constant. These lamps may be as reliable as standards as the others, as the change of resistance is very small and the change in candle-power when used at constant watts is practically nothing. The mean deviation of the separate measurements of candle-power from a straight line drawn through the first and last measurements, in the case of the four lamps burned 250 hours is only a few hundredths of a candle-power.

In addition to these two lots of lamps which had thus been seasoned and standardized with unusual care, there were a few others that were abundantly good for commercial standards, and a few were discarded as more or less defective.

In Fig. 5 are given the life curves of some of the lamps of the first and second class. The first two lamps are as follows:

1st lamp { At 40 hours, 106.0 volts, 0.5740 amperes, 14.98 c-p.
At 80 hours, 106.0 volts, 0.5740 amperes, 15.03 c-p.

2nd lamp { At 40 hours, 108.0 volts, 0.5840 amperes, 16.20 c-p.
At 80 hours, 108.0 volts, 0.5840 amperes, 16.24 c-p.

The filaments were unchanged after 40 hours of burning, and the light is practically constant.

The next two lamps are not yet at their maximum candle-power at constant voltage, but at constant watts the light is given by the dotted curves, and is contant from 70 to 110 hours.

The next two lamps have passed their maximum light at constant voltage, that is, their resistance is increasing. If, however,

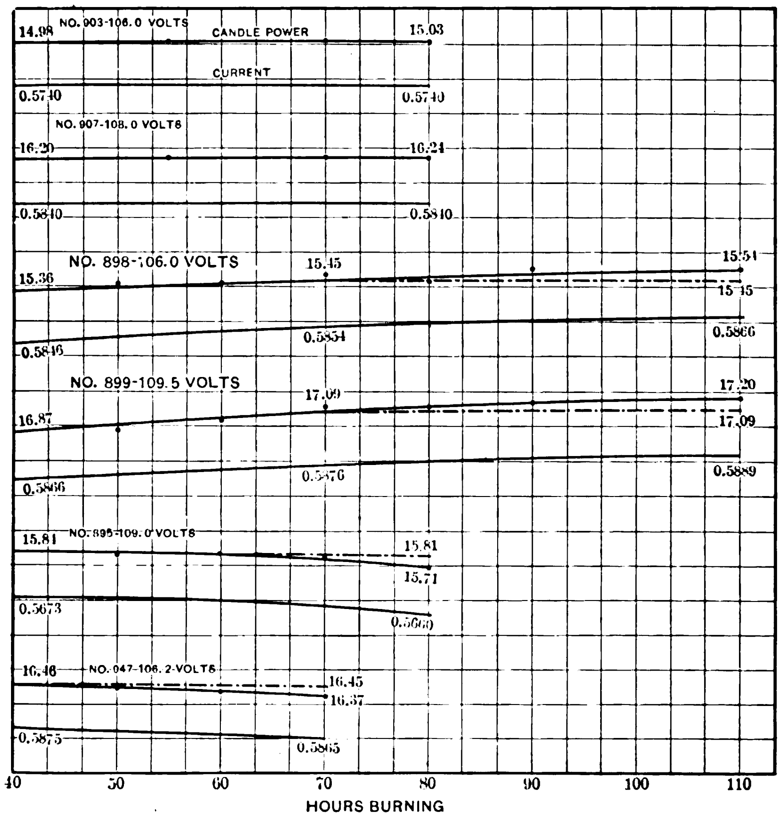


FIG. 5

the voltage be increased to keep the watts constant the light is found to have remained constant from the 40 hour starting point. These curves are given to show how important it is in the case of precision photometric work to keep a careful record of the current, and then to change the voltage, if the resistance of the filament changes, so as to keep the watts constant.

As to the precision of measurement of carbon-filament elec-

tric lamps, on such a precision photometer as here described, the mean error of the determination of candle-power on any lamp at one time is about 0.2 per cent, whereas the mean error of the average value of 6 lamps measured at one time is about 0.1 per cent. If a group of six lamps be measured by four different experienced observers, as is done at the Bureau, the mean of the four will of course be still less in error. These figures are the results of a large number of experiments with rotating standards, of the same color, and stationary standards may be measured with substantially the same accuracy.

With such precision of measurement and a life performance of standards such as described above, it would seem as though the unit of candle power not only of a commercial laboratory but also of a national standardizing laboratory, or even of a group of national standardizing laboratories, could be maintained for a long period of years by carbon filament incandescent lamps far more constant than could possibly be done with flame standards or any other form of primary standard as yet proposed.

A paper to be presented at the 27th Annual Convention of the American Institute of Electrical Engineers, Jefferson, N. H., June 28–July 1, 1910.

SOME RECENT DEVELOPMENTS IN EXACT ALTERNATING-CURRENT MEASUREMENTS

BY CLAYTON H. SHARP AND WILLIAM W. CRAWFORD

In common with other laboratories, the Electrical Testing Laboratories have found that the more exacting demands of modern engineering work for precise alternating current measurements, have outstripped the capabilities of the older methods of measurements. It is the purpose of this paper to describe certain of the new methods and apparatus which have been developed in response to these demands.

The development of a method of measurement involves first, the establishment of certain theoretical relations between the quantity to be measured and known quantities, and second, the design of the apparatus for the application of the method. If the method together with the apparatus is such that it can be successfully applied to making accurate measurements under the conditions of ordinary engineering work, its field of usefulness is greatly extended, for it is often desirable to make tests outside the laboratory.

There are many important measurements which are outside the range of ordinary commercial instruments. Among these are the measurement of electrostatic capacities, self and mutual inductances, and of extremely large and extremely small values of voltage, current, and power. For the measurement of large quantities, the range of ordinary instruments is extended by means of voltage and current transformers, but the measurement of the ratios of the transformers presents a problem requiring special methods.

It is well recognized that zero methods furnish possibilities for precise measurements beyond the capabilities of deflecting

instruments, inasmuch as the quantity to be measured is balanced against some other more easily measured quantity, and the inherent errors due to the mechanical moving parts,—springs, suspensions, divided scales, etc., of indicating instruments, are avoided. In precise direct-current work, zero methods are used to the exclusion of all others.

In alternating-current measurements, zero methods have not been used to so great an extent, largely because of the lack of proper facilities for applying them when using currents of commercial frequencies. The necessity for zero methods, is however greater in alternating-current measurements than in direct-current measurements; first, on account of the limitations of alternating-current indicating instruments, and second, because of the practical impossibility of obtaining alternating currents as steady as the direct currents furnished by the storage battery.

The difficulty of applying zero methods to alternating currents lies chiefly in the instrument used as a detector in obtaining a balance. If an electrodynamometer is used as a zero instrument, the deflection falling off as the square of the current results in low sensitiveness as the current approaches zero. By separately exciting one of the coils, the sensitiveness may be greatly increased but it is then necessary to provide means for bringing the excitation in phase with the current to be measured.

The telephone under proper conditions, is very sensitive as a zero detector. Its great advantage is its simplicity and cheapness, but when working on the commercial frequencies of 60 and 25 cycles per second, its sensitiveness is for physiological reasons, very low.

Various alternating-current galvanometers have been made, but none of them has come into wide commercial application. The vibration galvanometer when properly tuned, is very sensitive; but being a delicate suspension instrument, it is not suited to all locations, and with a change in frequency, a great decrease in sensibility occurs.

The Synchronous Reversing Key

The idea of rectifying the alternating current and passing the rectified current through a direct-current galvanometer, or detector, is not new. It underlies the secohmmeter, which has been used for many years. More recently, attempts have been made to use as a zero detector a direct current galvano-

meter with an ordinary brush-contact commutator on the generator shaft, or on the shaft of a synchronous motor driven by current from the same source as that to be measured. This plan has been tried and found to be capable of convenient application in many cases, but great difficulty has been found with it due to the fact that the apparent resistance of the sliding-brush contacts under working conditions tends to become very high as the current falls to a low value.

Platinum contact keys used in galvanometer circuits being known to be free from this difficulty, the next step was to construct a rectifier consisting of a reversing key with platinum contacts operated at synchronous speed by means of a synchronous motor and cam.

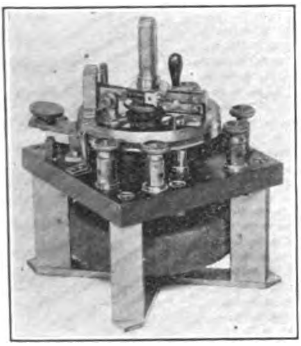


FIG. 1—Synchronous reversing key No. 1

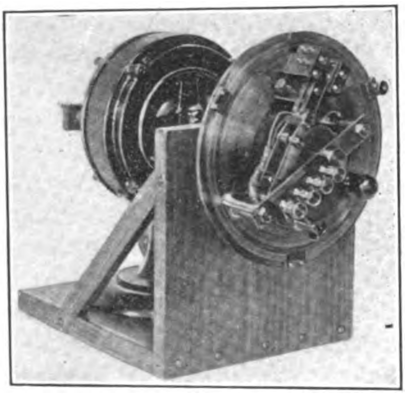


FIG. 2—Synchronous reversing key No. 2

Means are provided for adjusting the angular position of the contacts with respect to the poles of the motor, so that the reversal occurs at any desired phase of the current. By properly locating the contact setting, the galvanometer may be made to respond to any given component of the current while it is insensitive to the component in quadrature with it.

Figs. 1 and 2 shows two rectifiers which have been constructed. The first is attached to a small four-pole synchronous motor of the type described by Mr. L. T. Robinson before the last year's Convention.* This rectifier, while fairly satisfactory, had certain defects in the design of the key, and was greatly handi-

* PROCEEDINGS A. I. E. E., July 1909, p. 1000.

capped due to the impossibility of adequately insulating the key circuits from the motor circuits. Rectifier No. 2 is driven by a larger eight-pole motor which while having the disadvantage of requiring a direct-current field, has a larger torque, permitting the construction of the key with heavier moving parts and greater durability.

The insulation of the motor circuits from the galvanometer circuit is of the greatest importance. An extremely small electrostatic capacity or surface leakage between them may introduce serious errors in measurement. Accordingly, in rectifier No. 2, the key was mounted on a separate bed plate insulated entirely from the motor. By grounding the bed plate of the key to the proper point in the measuring circuit, whatever residual leakage occurs may be led away in such a manner as not to affect the galvanometer.

It has been found in practice that this apparatus gives very good results. The oscillating lever and contacts will operate satisfactorily on a frequency of 60 cycles or more. The wear on the contacts is practically nil, provided that the surfaces are broad enough. The sensitiveness of the galvanometer is practically the same on alternating currents as on direct currents. Theoretically the ratio of the deflections for the same effective value of current should be the form-factor of the alternating-current wave. Due to various minor imperfections in the apparatus so far constructed, however the method is not accurate as a means for the determination of form-factors.

The apparatus places alternating-current measurements on the same basis as direct-current measurements with respect to the sensibility of the galvanometer. Using the galvanometer as a deflection instrument, such quantities as the drop in a short length of iron rail or in a bond carrying alternating current, the measurement of the leakage and charging current of a few insulators, or of a short length of cable, etc., may be easily measured The mechanical imperfections of the rectifiers so far constructed. are such that the calibration as a deflection instrument is not accurate, due to the reversal not taking place exactly at the zero of the wave, but when the calibration is made under the conditions of use, it will be sufficiently accurate for the class of measurements involved. Since the deflection obtained represents the average value of the voltage, any uncertainty in the wave form introduces a corresponding uncertainty in the calculation of the effective value. The wave form may, however,

be approximately determined by taking the deflections with a series of settings of the contacts, as is explained later.

In the greater part of the work a portable galvanometer, such as a Paul single pivot galvanometer, giving one division deflection for one microampere and having 50 ohms resistance, gives sufficient sensitiveness. With a galvanometer of this type, the use of a telescope and scale is avoided, and vibration does not effect the measurements. This makes it possible to set up the apparatus in practically any location; *e.g.* in a power house, and to make measurements which with more delicate apparatus would be impracticable. An ordinary portable millivoltmeter makes a very good galvanometer for measurements not requiring the maximum sensibility.

Current Transformer Ratios

The method of introducing low resistances in the primary and secondary circuits and balancing the drops against each other by means of a zero detector, has been tried by various experimenters. The ratio of transformation is the inverse ratio of the resistances. Due to the slight phase difference between the two currents, there will remain, when the drops are adjusted to equality, a slight voltage, practically 90 degrees in phase from the resistance drops. The effect of this voltage may be eliminated by properly setting the angular position of the contacts, but unless the phase angle of the transformer is very small, it is difficult to set the contacts with sufficient accuracy.

In order to obtain a more accurate value of the ratio and at the same time to measure the phase angle, some means of bringing the two drops in phase is needed. Several methods of doing this which have been developed at the Electrical Testing Laboratories were described before last year's Convention.* The one finally adopted as most desirable is shown in Fig. 3. The primary and secondary resistances are R′ and R″, respectively. A mutual inductance, M is introduced which adds to the drop in R″ a small voltage, a, in quadrature with it, thus balancing the phase displacement. The double adjustment is made as follows:

By trial, the angular position of the contacts is found in which the galvanometer is sensitive only to changes in the secondary resistance R'' and not to changes in the inductance. The resistance balance is made with this setting. The contacts are then shifted through 90 electrical degrees, and the inductance

* Proceedings A. I. E. E., Oct. 1909, p. 1356.

is adjusted until the inductive drop has been annulled. The contacts are then returned to the original position for a check on the resistance setting.

The ratio and phase angle are computed from the following formulæ:

$$\frac{I'}{I''} = \frac{R''}{R'} \sqrt{1 + \left\{ \frac{2\pi f M}{R''} \right\}^2}$$

$$\tan \gamma = \frac{2\pi f M}{R''}$$

When the phase angle is less than two deg. the correction term in the ratio formula may be neglected. In practice, the calculations are simplified by the use of curves which give the results directly from the readings.

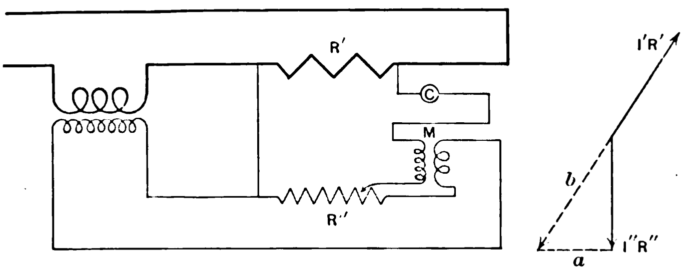


FIG. 3—Connections for ratio and phase angle test of current transformers

Sensitiveness. The minimum value of secondary resistance used is 0.025 ohm. The drop is then 0.125 volts at full load. With a portable galvanometer of the type above described the balance may theoretically be obtained within 5 microvolts in 125,000, or to one part in 25,000, by setting to 0.1 division. At 10 per cent load, a balance may be obtained within one part in 2500. The accuracy of measurement is therefore limited not by the sensitiveness of the galvanometer, but by the accuracy of calibration of the resistances, leakage and stray fields, etc. It is found that in measuring the same transformer at different times, the results will, barring mistakes, invariably agree within 0.1 per cent in ratio, and a few minutes in phase angle, at full load.

Leakage. Due to the necessity of connecting the secondary and primary circuits together, trouble is experienced from leakage

and electrostatic effects. If the apparatus is at a moderate voltage above the ground, leakage may occur from the primary through the cross connection into the secondary and thence to earth. Referring to Fig. 3, it will be seen that very little of this current will pass through the galvanometer, the direct connection between R' and R'' furnishing a path of much lower resistance. The leakage current will, however, add to the current in R'' and may if large introduce an error. The amount of the leakage current is determined by removing one connection so that the total leakage must pass through the galvanometer.

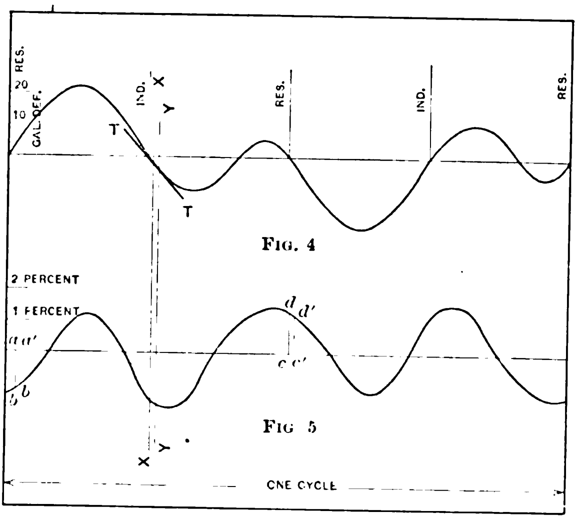
Measurement of Distortion of Wave Form. An interesting property of the method is that, when used in connection with the rectifier, a determination of the relative wave form of the primary and secondary currents may be made without additional apparatus.

If the primary current has a sine wave form, and no distortion is introduced by the transformer, balancing in the " resistance " and " inductance " positions, as previously described, will insure that when the contacts are shifted to intermediate positions, the deflection will remain at zero, since the secondary wave will balance the primary wave at all points in the cycle. If, however, the primary and secondary wave forms are different, the two waves will not balance at all points in the cycle, and with intermediate settings of the contacts, a deflection will be obtained on the galvanometer. From the curve of these deflections, the difference in wave form between the primary and the secondary currents may be derived.

Fig. 4 shows a curve of deflections obtained on a transformer which on account of certain features of design showed an unusually large distortion. The test was made under severe conditions of load in order to magnify the effect. Fig. 5 shows the wave form, as derived from the above curve, of the distortion introduced into the secondary current. Evidently, the triple frequency component is predominant. The maximum ordinate is about 1.5 per cent of the secondary current. The method of derivation is as follows:

Since the rectifier closes the galvanometer circuit in one direction during a half cycle and in the reverse direction during the next half-cycle, the deflection represents the average current during a half cycle. In Fig. 5, with the contacts set to reverse at a and c, the galvanometer would be sensitive to a sine current whose maximum is at XX. On a distorted wave form, its

deflection represents the area of the curve between a b and c d. When the contacts are shifted to reverse at a' and c', the change in deflection represents twice the area $a\,b\,b'\,a'$, and gives a measure of the ordinate of the curve at this point. This change in deflection is equal to the difference in the ordinates at X X and Y Y, in Fig. 4. The wave form of the distortion introduced in the secondary is therefore derived by taking the differences of successive ordinates of the observed curve of deflections, or more accurately, by taking the slopes of the observed curve at various points. Corresponding points on the observed and derived curves are 90 degrees apart.



FIGS. 4 and 5—Distortion curves of current transformer

The actual values of the ordinates of the distortion curve may be computed from the following formula:

$$x = \frac{d}{4\,d'}$$

where x = ordinate of distortion curve expressed as a percentage of the total secondary current.

d = slope of deflection curve expressed in divisions per cycle.

d' = deflection produced with the resistance setting of the contacts, by one per cent change in the secondary resistance.

Design of Apparatus. In designing apparatus for measuring current transformer ratios, an important point to be considered is the impedance introduced in the secondary circuit. Any appreciable impedance raises the voltage which must be supplied by the transformer, and thus has an influence on the ratio of transformation. In practice, transformers are often used with a single instrument of very low impedance and with very short leads, precluding the use of measuring apparatus of considerable impedance.

In the apparatus designed, the secondary resistance and primary of the mutual inductance combined amount to 0.1 ohm, and the leads introduce 0.05 ohm more, making the total 0.15 ohm. Where results are required with less resistance the small correction necessary may be easily determined by extrapolation from tests with higher values of resistance.

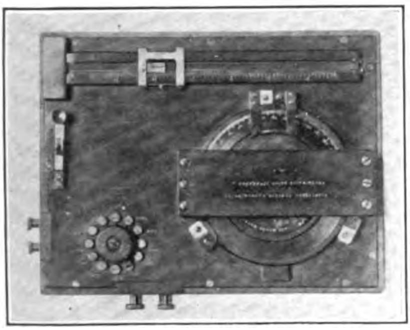


FIG. 6—Slide wire and mutual inductance

In order to save trouble in making connections, the secondary resistance and mutual inductance were constructed as a unit. The apparatus is shown in Fig. 6. A fixed resistance is used from which taps are brought out every 0.05 ohm to a dial switch. The fine adjustment is obtained by means of slide wire which shunts a part of the main resistance. The advantage of this arrangement is that sliding contacts are not introduced in the current circuit and that the amount of impedance in the secondary is always the same. The slide wire has a total resistance of 0.06 ohm, so that it overlaps the fixed steps by 0.005 ohm in either direction. This facilitates making settings near an even value. Where a number of taps are to be brought out, and where a slide wire is involved, it is difficult to make the resistance perfectly non-inductive. Loops are avoided in the leads by binding them close to the doubled manganin strip. To make the slide wire non-inductive, it is made double the required length and the unused half is brought back under the used half. The sliding contact bridges from the slide wire to a second wire lying close to it. These refinements, while they may not al-

ways be necessary, are advisable to insure accurate results in phase angle measurements.

Astatic Mutual Inductance. The mutual inductance requires careful design, the following qualities being desirable:

Long scale.
Freedom from stray field effects.
Low impedance of primary circuit.
Freedom from eddy current effects.
Permanence and reliability of calibration.
Easy adjustment.

The arrangement of coils adopted is shown in Fig. 7-a and 7-b. In Fig. 7-a, the coils are in the position of maximum mutual inductance. Rotating the hard rubber disk on which the secondary coils are mounted, through 180 degrees brings the coils to the position shown in Fig. 7-b. The lines of force from the primary coils then thread the secondary coils in a reverse direc-

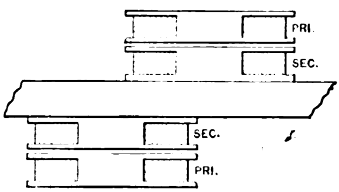


FIG. 7a—Position of maximum positive mutual inductance

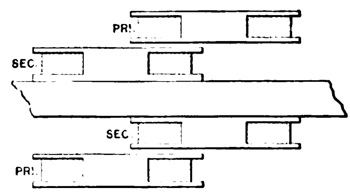


FIG. 7b—Position of maximum negative mutual inductance

tion, resulting in a negative value of mutual inductance. Between the two positions a zero is found. The positive maximum is larger than the negative maximum, which is not undesirable in the measurement of transformer ratios. Four coils being used, the inductance may be made astatic so that the effect of stray fields is small. A strong and non-uniform field may induce an error, but by keeping all instruments and heavy current conductors at a distance from the mutual inductance, or by taking direct and reversed readings, the effect may be eliminated. The primary may be constructed with a very small number of turns; the desired value of induced e.m.f. is obtained by constructing the secondary with a much larger number of turns. In order to obviate eddy currents in the primary, the coils are wound with small wire, a number of windings being placed in parallel.

The mechanical details are shown in Fig. 8. Due to the loca-

tion of the coils, it is impossible to mount the disk on a pivot, and a special three-point peripheral grooved bearing is therefore employed. The construction is satisfactory with respect to rigidity and permanency, no measurable difference having been found in calibration since the apparatus was finished. Although the bearing works stiffly, there is no great difficulty in making an exact setting.

Test Table. A set of resistance and inductance coils is provided for introduction into the secondary to duplicate the effects of various combinations of instruments. The steps are so small as to furnish practically a continuous variation.

Fig. 9 is an illustration of the entire apparatus set up for use.

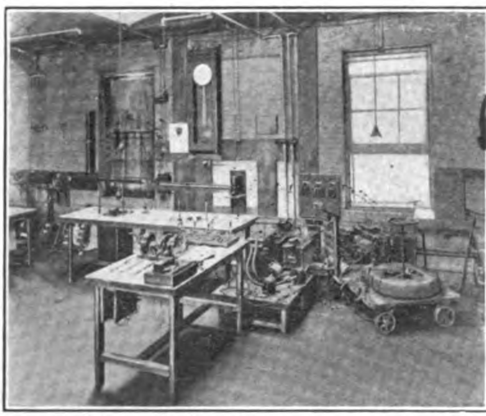


FIG. 9—Complete apparatus for testing current transformers

The complete connections of the testing table are shown in Fig. 10. This table is designed with a view to the maximum convenience in laboratory use, but all measuring apparatus can be removed from it and used in any desired location.

METHOD USING MUTUAL INDUCTANCES

The following additional method of measuring current transformer ratios has been considered, but has not been tried owing to the fact that the present apparatus suits the requirements. It offers, however, certain important advantages.

In the suggested method, mutual inductances are substituted for the resistances previously used. The electromotive forces induced in the secondaries are balanced against each other, one

of the mutual inductances being variable. The connections are shown in Fig. 11. The phase difference is compensated by a resistance drop introduced by a slide wire, S, carrying the secondary current. The ratio and phase angle are given by the following formulas.

$$\text{Ratio} = \frac{M''}{M'} \sqrt{1+\tan^2 \gamma}$$

$$\tan \gamma = \frac{R_s}{2 \pi f M''}$$

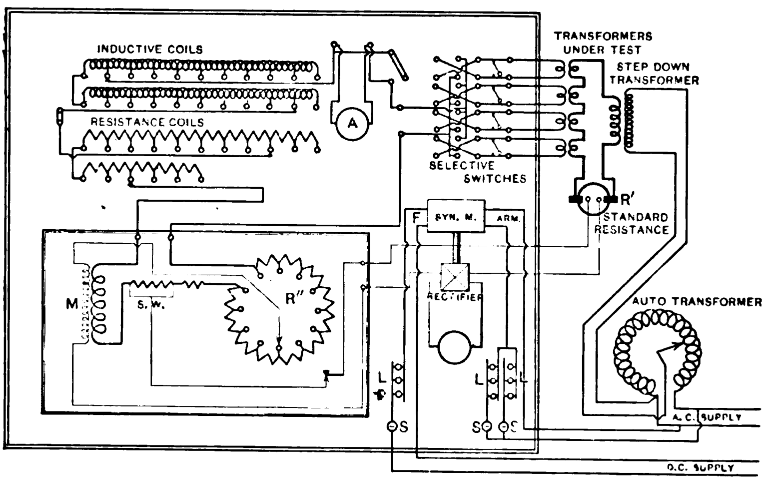


FIG. 10—Connections of current transformer testing table

The advantages of this method over the method using resistances are:

(a) The energy expended in the apparatus may be made exceedingly small.

(b) By properly proportioning the numbers of primary and secondary turns on the mutual inductances, it is possible to obtain electromotive forces in the galvanometer circuit which are much greater than the drops in the primary coils hence greater sensitiveness can be obtained without the introduction of an undue impedance in the secondary of the transformer under test.

(c) It is not necessary to connect the primary and the secondary circuits together, and leakage effects are therefore reduced.

The disadvantages of the proposed method are:

(*a*) Mutual inductances are not so easily calibrated as resistances.

(*b*) It is difficult to construct accurate mutual inductances for large currents, although probably not more so than in the case of resistances.

(*c*) Stray field effects will influence the ratio directly, requiring astatic construction of the mutual inductances and great pains with the location of the leads carrying heavy currents.

Measurement of Magnetizing Currents

As a means of determining the ratio and phase angle of current transformers, where apparatus for their direct measurement is not available, or as a check on direct measurements, the value of computations from magnetizing current determinations is well recognized. Assuming a certain value of secondary current.

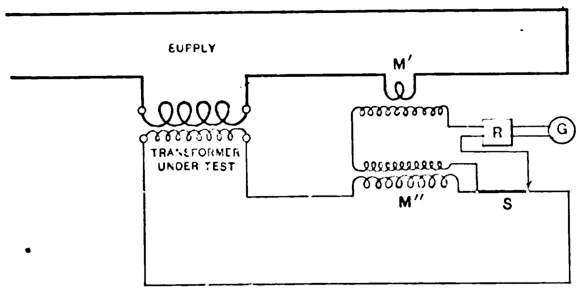


Fig 11—Measurement of current transformer ratio by means of mutual inductances

the electromotive force which must be furnished by the transformer, and the phase relation of this electromotive force to the current, can be computed from the resistance and reactance of the secondary circuit. At the given voltage, the value of the magnetizing current and its phase relation to the voltage is determined. The primary current then includes, first, a current sufficient to make the primary ampere turns equal to the secondary ampere turns, and second, the magnetizing current which is combined with the load component in a certain phase relation which is the resultant of the phase angle between the load current and the voltage, and the phase angle between the voltage and the magnetizing current.

The magnetizing current is measured on open circuit the voltage being adjusted to the value corresponding to a given

load of the transformer. It is best measured by supplying the current to the secondary or low current winding and computing the results in terms of the primary.

For the determination of the magnetizing current, a sensitive electrodynamometer may be used. To obtain both the magnitude and phase relation, the most obvious method is to use the electrodynamometer as an ammeter to measure the total current, and as a wattmeter to measure the power component. A preferable method is to determine the power and wattless components by separately exciting the electro-dynamometer alternately from the phases of the two-phase circuit (Fig. 12). The electrodynamometer is calibrated by substituting for the transformer a known non-inductive resistance. For very low voltages, a step-down transformer of known ratio may be introduced. The voltage is then measured on the high side and the current on the low side.

These measurements may also be made by means of the rectifier

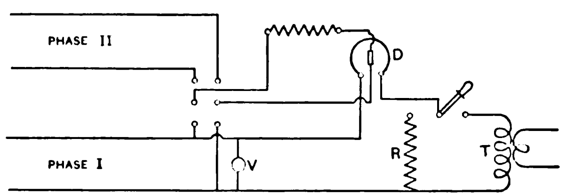


FIG. 12—Measurement of core loss by means of electrodynamometer

by inserting the transformer in an inductance bridge and ascertaining the equivalent alternating-current resistance and the reactance under the working conditions of voltage and frequency. The distortion of the wave form will have the same effect as in a ratio measurement and may be determined in the same way.

VOLTAGE TRANSFORMERS

A number of methods for measuring the ratios and phase angles of voltage transformers have been used. The simplest method is to use a rectifier; as shown in Fig. 13, R and r are high resistances connected in series to the primary circuit. A balance being obtained by varying r, the ratio of primary to secondary voltage is

$$\frac{R+r}{r}$$

As in the case of current transformer measurements, it is necessary either to pay strict attention to the setting of the contacts or to use some means of bringing the primary and secondary voltages in phase. The latter procedure is preferable. Various methods of balancing the phase displacement by introducing capacities or self or mutual inductances, may be used.

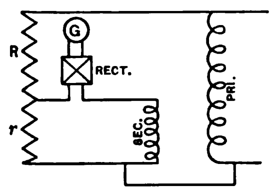


Fig. 13—Measurement of voltage transformer ratio by means of rectifier

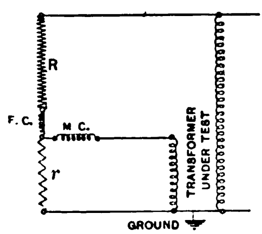


Fig. 15—Measurement of voltage transformer ratio using electro-dynamometer

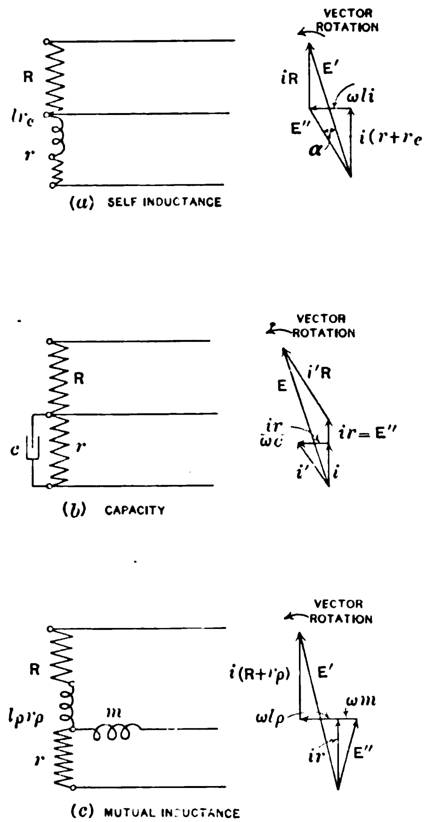


Fig. 14—Means of balancing phase displacement

A few of these are illustrated in Fig. 14. The method using a mutual inductance is probably the most satisfactory.

Methods employing a sensitive electrodynamometer similar to those used in other laboratories* have been tried. It has

* L. T. Robinson, Proceedings A. I. E. E., July 1909.
Agnew & Fitch, Bulletin Bur. of Stds., Vol. 6 No. 2

been found possible to simplify these methods by the employment of one electrodynamometer only in phase angle tests whereas previously two electrodynamometers have been employed. The connections are shown in Figs. 15 and 16. In Fig. 15, the fine wire fixed coil of the electrodynamometer is excited by inserting it in series with the bridge resistances. The excitation being in phase with the voltage, the phase angle of the transformer (if small) does not affect the measurement.

In Fig. 16, by using a two-phase circuit, the electrodynamometer is first excited in phase with the voltage of the transformer under test and the adjustment of resistances to obtain the ratio is made. The excitation is then shifted to the other

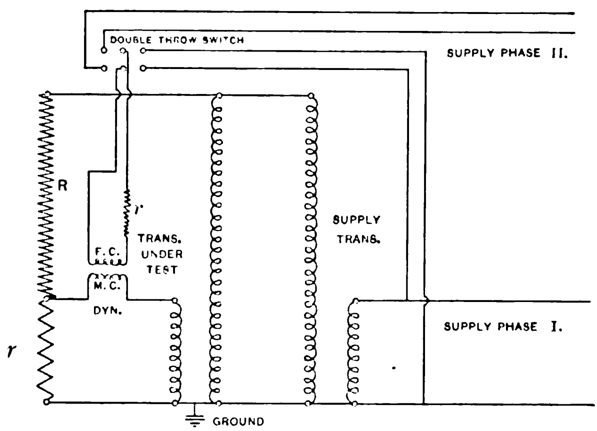


FIG. 16—Measurement of voltage transformer ratio and phase angle using electrodynamometer

phase and a deflection is obtained which is a measurement of the phase difference between the primary and secondary voltages. For the evaluation of the phase angle, the electrodynamometer is calibrated with its excitation in phase with the voltage, by altering r a small amount, r', and noting the change in deflection. Then

$$\tan\beta = \frac{d''}{d'} \quad \frac{r'}{r} \quad \frac{R}{R+r}$$

where d'' and d' are the deflections under test and calibration conditions respectively.

Means of Loading Transformers at Various Power Factors. In the testing of voltage transformers, it is necessary to obtain various loads at various power factors representing the equivalent of the instruments to which the transformers are to be connected in use. The method given here was devised to permit any load at any desired power factor to be obtained without the necessity of constructing a large number of inductance coils of various values. The connections are shown in Fig. 17. Two transformers are required which have approximately the same ratio. Transformer No. 2 is connected to one phase of a two-phase circuit and is used as a step-down transformer to supply energy to transformer No. 1, which is under test. A load on transformer No 1. at unity power factor is obtained by means of a lamp bank connected directly across its terminals. The load at zero power

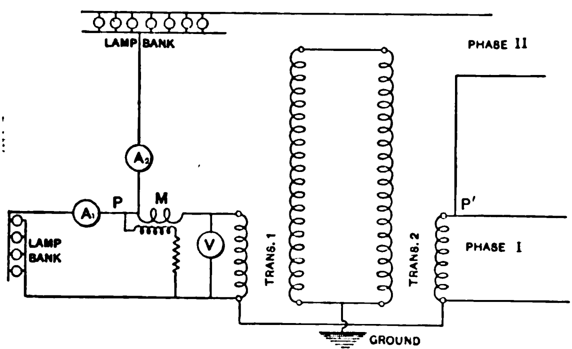


FIG. 17—Method of loading transformer at various power factors

factor is obtained by introducing the second phase of the two-phase circuit between the points P, and P^1, in series with a lamp bank. If the transformers are connected with the proper polarity, these points are at the same potential so that the current flowing is determined purely by the voltage of phase two. The ammeters A_1 and A_2 respectively measure the power and wattless components of the load current, enabling their independent adjustment. The wattmeter M furnishes a check on the power factor. This method of loading is suggested as a possibility for the loading of power transformers for regulation tests, etc., at various power factors. The pumping back method could be used and the load current caused to circulate by two low voltage transformers connected to the two phases.

Voltage Ratio of Current Transformers. It is often necessary when analyzing the results of current transformer tests, to know

the ratio between the primary and secondary turns and it is important to be able to determine this value by test, since due to errors in manufacture, the number of turns may differ from that intended.

The ratio of turns is determined by measuring the voltage ratio in the same manner as for voltage transformers. Four or five volts is impressed on the secondary and a fraction of this is balanced against the e.m.f. induced in the primary.

To obtain the true ratio of turns, it is necessary to correct for the drop in the low-current winding due to the magnetizing current. If no magnetizing current determination has been made, an approximate value may be obtained by the following procedure. With the connections shown in Fig. 18, the milliammeter indicates the resultant of the magnetizing current and of the current taken by the voltmeter. The phase relation of this current to the voltage is not known. Referring to Fig. 19,

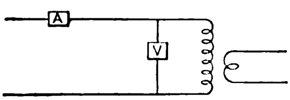


FIG. 18

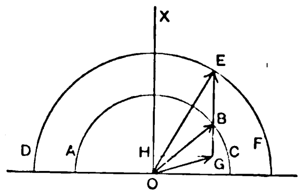


FIG. 19

it may be considered to be represented by a vector from the point O, whose end is somewhere in the arc $A\ B\ C$, which is laid out to a suitable scale. $O\ X$ represents the voltage.

A known non-inductive resistance is connected in parallel with the voltmeter and the increased current indicated by the ammeter is observed. The arc $D\ E\ F$ is laid off with a radius equal to this current. The vector difference between this current and the initial current will be the current taken by the non-inductive resistance which is in phase with $O\ X$. Finding a point where the vertical distance between the two curves is equal to the computed value of the current in the added resistance, the points B and E are determined. $O\ B$ is then the initial current. By subtracting from this the current taken by the voltmeter (equal to $B\ G$) the magnetizing current $O\ G$ is determined. $O\ H$ is then the component in phase with the voltage and this, together with the resistance of the winding, enables computing the correction to the observed ratio.

The Alternating-Current Potentiometer.

The amount of energy required by alternating-current indicating instruments prohibits their use directly in measuring very low alternating voltages. A separate circuit may, however, be obtained from the same generator and the unknown voltage measured by balancing it against a known fraction of a higher voltage which can be measured accurately by means of indicating instruments. The connections are shown in Fig. 20, in which the "standard voltage" is obtained on the line *C D*, and the unknown voltage on the line *A B*. A balance is obtained by adjusting r_1 and the phase relation. The unknown voltage is then

$$\frac{r_1}{r_1 + r_2} \quad \text{of the voltage on } C\,D.$$

The sensitiveness of the rectifier is sufficient to enable a voltage

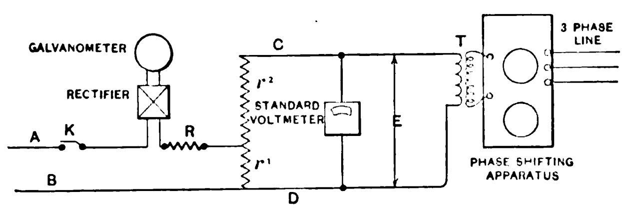


Fig. 20—Alternating current potentiometer

of a few millivolts to be measured quite accurately. The same method may be used to measure alternating currents of any desired magnitude by the use of a non-inductive shunt, and has the advantage that the necessary drop in the shunt is very small.

Methods of Adjusting Phase Relations. For obtaining a varying phase relation such as is needed in the alternating-current potentiometer arrangement, and in many other classes of tests notably test of wattmeters and watt-hour meters on low power-factors, the following methods have been found convenient. Using a three-phase circuit, (Fig. 21) a slide-wire rheostat is connected across two of the phases. The voltage circuit is obtained from the third phase and from the sliding contact on the rheostat. This arrangement furnishes a gradual shift of 60 deg. and phase relations beyond this range may be obtained by connecting the rheostat to the different phases. The method is not suited to cases where the voltage circuit draws a large

amount of current and should not be used in tests on induction meters, since introducing resistance in series with the voltage circuits may cause errors. To obviate this difficulty, an apparatus using a variable auto-transformer instead of a resistance, has been devised. The variable auto-transformer consists simply of a laminated iron ring with a uniform layer of wire on it. On the outer surface of the ring, the insulation of the wire is removed making a continuous contact surface to which connection is made by means of soft carbon brushes. The connections are the same as those shown in Fig. 21. A second auto-transformer is introduced to enable the adjustment of the voltage. By means of a cam and lever arrangement, a second contact on the voltage regulating transformer is made to compensate for variations of voltage resulting from the phase shift.

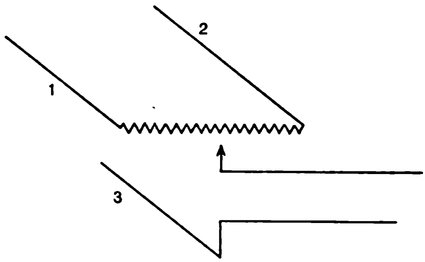


FIG. 21—Phase adjustment

Variable auto-transformers of the type described above are found very useful in the laboratory for a variety of purposes. In Fig. 9 at the right-hand side, there may be seen a transformer of large capacity, designed to effect the gradual regulation of the voltage in high-tension testing, and used in this case to regulate the primary voltage of the step-down transformer supplying current to the transformers under test. On account of the large magnetic leakage under load, indicating instruments or other apparatus susceptible to stray field effects should not be used near the transformer.

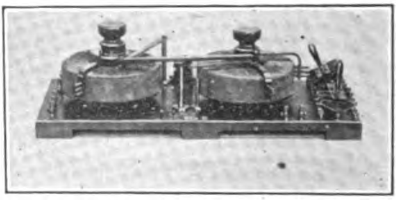


FIG. 22—Phase shifting apparatus

MEASUREMENTS OF INDUCTANCES, CAPACITIES AND ALTERNATING CURRENT RESISTANCES

Various accurate methods of comparing inductances and capacities by means of alternating currents, using modifications of the Wheatstone bridge, are known and used. For measurements of this class, the synchronous reversing key is very serviceable. In balancing on alternating currents, a double adjustment

is necessary, inasmuch as a balance must be obtained of the resistances as well as the reactances. One method of making the double adjustment is to balance the bridge on direct currents by varying the resistances, and then to balance on alternating currents by varying the inductances and capacities only. In circuits where skin effect, eddy currents, dielectric losses, iron losses, etc. are present, the equivalent resistance to alternating current is different from the resistance to direct current, and further adjustment of the resistance is necessary. As explained before, double adjustments of this character are made with great ease using the rectifier, by setting the contacts for sensitiveness either to the resistance or reactance components.

Heavy Current Non-Inductive Shunts.

The tube form of resistance has many advantages and should give practically negligible values of inductance. It has, however, been found that resistances having very low inductances can be constructed without resort to the tube form provided that suitable precautions are taken in leading in the heavy currents.

In resistances designed for very heavy currents, and to furnish a large drop, a large amount of power is to be dissipated. Designs employing flat sheets allow a greater amount of cooling surface to be obtained and sheet designs may in some cases be preferable even though more complicated in construction.

A series of resistances of the general characteristics given in the following table have been designed. Each resistance has taps brought out at ½, 1/5, 1/10, etc. of its value.

TABLE OF DATA ON RESISTANCES

Amperes	Volts	Ohms	Watts	Temperature rise, deg. cent.	Size	Weight lb.
200	2	0.01	400	15	10 in. x 9 in. cylinder	18
1000	1	0.001	1000	14.5	10 in. x 10 in. x 18 in.	80
5000	1.2	0.00024	6000	27	16 in. x 15½ in. x 18 in.	220

Only the largest will be described in detail, as its construction typifies the others and it has certain interesting properties not found in the other resistances to as marked a degree.

The construction is shown in Fig. 23. The current terminals consist of two heavy copper blocks, A and B, which lie horizon-

tally on the top of the containing case. A series of bars, *a*, *b*, *c*, etc. are silver soldered to the terminal blocks, alternate bars being attached to the positive and negative terminals respectively. These bars extend directly downward into the oil bath. Each sheet of resistance metal is folded double and its ends attached to two adjacent bars of opposite polarity. By this arrangement, each sheet is made non-inductive, and any desired number of sheets may be connected in parallel.

In order to bring out taps at fractional values, tongues are cut in one of the sheets to which the potential binding posts are attached. The arrangement of these potential leads to avoid loops susceptible to stray fields, is equally important with the

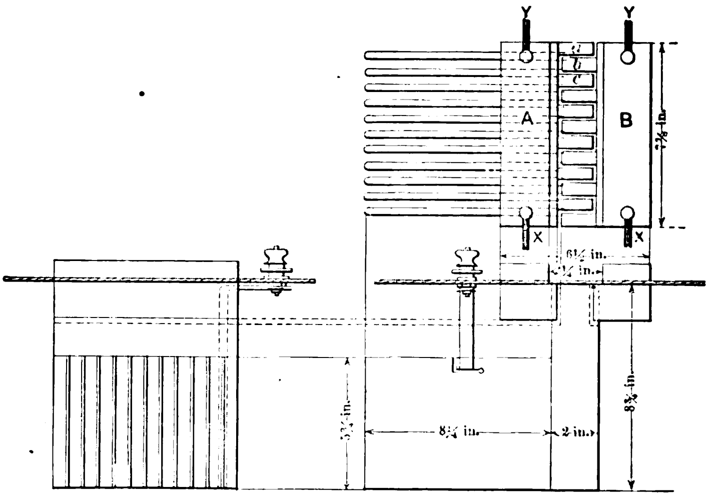


FIG. 23—5,000 ampere non-inductive shunt

non-inductive construction of the shunt itself. A double concentric binding post is used for the potential terminals.

The resistances are immersed in oil and cooled by a water jacket in the usual manner.

After some difficulty in determining the proper treatment for manganin sheets, pickling for 20 seconds in 50 per cent nitric acid has been found to remove the oxide and scale and give satisfactory results as regards temperature coefficient. The sheets are removed from the pickling solution, rinsed in warm water, dried in an air blast, and immediately shellacked. Before installing the insulating material and mechanical parts, the resistances are baked for 48 hours at 150 deg. cent.

Figs. 24 and 25 are photographs of the shunts assembled and taken apart, respectively.

Terminal blocks of the above described form introduce changes in resistance depending on the position of the current leads. The variations could be largely obviated by bringing out the

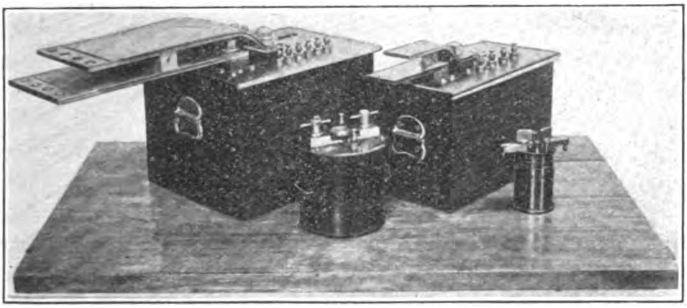


FIG. 24

potential taps from the middle sheet, but this is prevented by mechanical difficulties.

The phase angle between the current and the potential drop also varies with the position of the leads; in the 5000 ampere resistance which has 11 resistance sheets in parallel, the phase

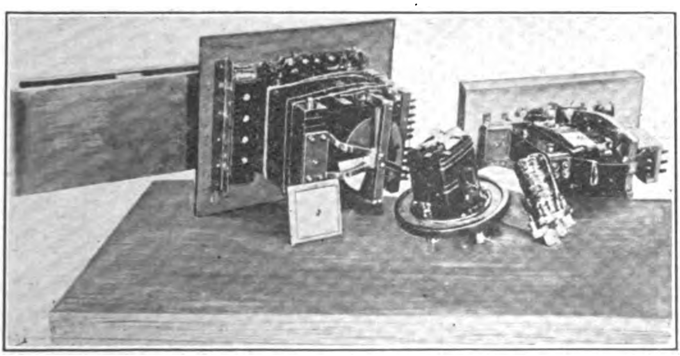


FIG. 25

angle at 60 cycles varied from +1 deg. to —1 deg., depending on whether the connections were placed in position XX or YY, Fig. 23. In order to remedy the variations in resistance and phase angles, a pair of extended connection plates, which may be clearly seen in Fig. 24 and 25, were installed. Using these plates

no variation in phase angle was found as long as the heavy current leads did not form a large loop near the resistance.

Comparison of Inductances of Heavy Current Resistances. The measurement of the residual inductance of an approximately non-inductive resistance is dependent upon comparison with resistances which are assumed to be non-inductive. In the case of very low resistances, this comparison is difficult because the only "non-inductive" resistances whose residual inductances can safely be neglected, are those of a comparatively high value (0.1 ohm or more). However, if a sufficiently accurate method is available, a series of comparisons starting from a resistance of high value and working toward the low resistances, will enable the desired results to be obtained. The method of comparing inductances by connecting two resistances in series, exciting

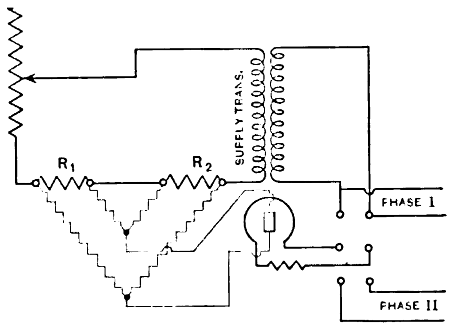


FIG. 26—Connections for measuring phase angles of shunts

the fixed coil of an electrodynamometer in quadrature with the current, and transferring the moving coil from one resistance to the other, was found unsatisfactory due to the fact that the phase relation between the excitation and the current in the resistances would not remain sufficiently constant for an accurate measurement. In this connection, it may be remarked that in order to obtain with sufficient certainty the phase angle of the 0.00002 tap of the 0.0002 ohm, 5000 ampere resistance, it is necessary to have a method capable of comparing phase angles to within 0.1 to 1 minute.

The second method tried was the use of the Kelvin double bridge with two equal variable self inductances inserted in series with the bridge arms. This method was found to be so susceptible to stray field effects that without the design of special apparatus, it could not be applied in practice.

The method which was finally adopted was that shown in Fig. 26. A Kelvin double bridge is used, but no attempt is made to balance the inductive effect. A Rowland electrodynamometer with separate excitation is used as a galvanometer. The resistances of the bridge are balanced with the excitation in phase with the current in the resistances under comparison. The excitation is then placed in quadrature with the current in the resistances and the deflection is noted. This deflection is a measure of the difference in phase angle between the two resistances. The rectifier and galvanometer might be used in the same manner.

The electrodynamometer is best calibrated by observing its sensitiveness to change in resistance when the excitation is in phase with the current. The inductance of the resistance under test is then obtained from the following formula.

$$\frac{X_1}{R_1} - \frac{X_2}{R_2} = \frac{d_1}{d_2} \frac{r}{R_0}$$

where

X_1 = inductive reactance of R_1
X_2 = inductive reactance of R_2
d_1 = deflection obtained in test
d_2 = deflection obtained in calibration
r = change in variable bridge arms corresponding to deflection d_2
R_0 = resistance of one of the variable arms of the bridge.

The sensitiveness of the Rowland electrodynamometer is such that using a Kelvin double bridge having 100 ohms in each fixed arm and 100 to 1000 ohms in the variable arms, and pushing the excitation to the limit, resistances having a drop of 0.1 volt may be compared to within 20 parts of reactance in 100,000 of resistance; or in other words, within about 0.6 minute. With a larger drop, a proportionately smaller phase angle may be measured.

This method has the advantage that it is independent of steadiness of the test circuit and is free from stray field effects. It is, however, essential to take precautions against leakage effects.

It is believed that the above described methods represent at least a small advance in the art of practical alternating-current measurements and that the results obtained by them will be of value to the engineer.

NOTE

The following paper is to be read at the 27th annual convention of the American Institute of Electrical Engineers at **Jefferson, N. H., June 28 – July 1, 1910.** This paper is to be presented under the auspices of the Electric Lighting Committee of the Institute. All those connected with the Institute and desiring to take part in the discussion of this paper may do so by being present at the meeting; or, if this is not possible, by sending in a written contribution.

Written contributions will be read at the meeting, time permitting, for which they are intended, either in full, in abstract, or as a part of a general statement giving a summary of the views of those taking the same position in the matter.

The principal object in getting out the paper in advance of the meeting is to enable and encourage those not in a position to attend the meetings to take part in the discussion by mail.

Contributions to the discussion of this paper should be mailed to **William L. Robb, Chairman Electric Lighting Committee, P. O. Box 592, Troy, N. Y.,** so that they will be received not later than June 23, 1910. Written contributions arriving within 30 days thereafter will be treated as if presented at the meeting.

(HARDING AND TOPPING)

A paper to be presented at the 27th Annual Convention of the American Institute of Electrical Engineers, Jefferson, N. H., June 28-July 1, 1910.

HEADLIGHT TESTS

BY C. FRANCIS HARDING AND A. N. TOPPING

The Indiana Railroad Commission, having been instructed to investigate and rule upon the compulsory use of more powerful headlights on steam locomotives operating in the State of Indiana, requested that both road tests and laboratory tests be carried out by the Engineering Schools of Purdue University, under the direction of Dean C. H. Benjamin, to determine the effect of such powerful headlights upon the interpretation of signals and upon the ability of the engineer to see and recognize obstacles upon the track in front of the locomotive. These tests which were carried out in the fall of 1909, consisted of two distinct groups as follows:

Group I. Road tests carried out on the St. Louis division of the Big Four Railroad for the purpose of comparing effects noted above of oil and electric headlights under actual operating conditions.

Group II. Laboratory and out-of-door tests carried on by the School of Electrical Engineering, Purdue University, under the direction of the authors to determine the photometric and spectrophotometric values of the above headlights as well as corresponding values for reflected light from signal roundels.

Since the completion of the above tests, the authors have carried out similar but more detailed tests on the above headlights together with a number of new types. In the belief of the authors of this paper that little has been made public along these lines, and that many engineers will be interested in this subject, the result of the latter tests are herein set forth prefaced by a brief abstract of the previous road tests.

Group I—Road Test

The following road tests were carried out during the night of October 13th, 1909 on the main line of the Big Four Railroad near Indianapolis, Indiana. Independent observations of signal aspects were taken by eleven observers seated in an open front observation car provided with headlights of different types placed at the same distance above the track as when mounted upon the locomotive. These observations were later compared and averaged and the results of the same briefly summarized. For detailed information regarding these road tests reference should be made to the paper by Dean C. H. Benjamin, read before the Western Railway Club and published in the April Proceedings.

Procedure. Test numbers 1 *to* 6 *inclusive were carried out in the following manner:*

The observation car was run back 5,000 feet from the home signal and a long blast of the locomotive whistle sounded. The colors of the home signal were then changed by a committee appointed for this purpose which remained at the signal. The observers in the observation car did not know the changes that were to be made in the colors. After sufficient time had elapsed for the signal to have been changed, the car was moved toward the home signal and short stops were made at predetermined intervals. At each stop, each of the eleven observers recorded independently the aspect of the home signal as he saw it. These records were collected after each test and later compared with one another and with the actual aspect of the signal in each case.

Test No. 1. *Observation of Colors of Home Signal at Distances Ranging from* 300 *to* 5,000 *Feet with Electric Headlight on Observation Car and the Opposing Electric Headlight* 200 *Feet in Front of Home Signal.*

From a comparison of the observations made of a number of different aspects in this test, where both headlights were of the electric type, it was noted that at distances of 3000 ft. or over the signals were invisible; that correct interpretation of the signals occurred at distances ranging from 800 to 1500 ft. from the home signal, depending upon the observer, and that at a distance of 800 ft. identification was practically unanimous. The interesting feature about this test is the fact that at dis-

tances of from 400 to 800 ft. many observers noted green signals where there was none displayed; at 600 ft. eight of the eleven observers recorded a green signal where no light existed, although at this point a green roundel had been placed with no signal light behind it. This so-called green phantom is the effect often noted by engineers operating locomotives with powerful headlights and is supposed to be due to the reflection of the light transmitted from the headlight to the unlighted green roundel and thence back to the eye of the observer or locomotive engineer. No such effect as this was noted in tests Nos. 2, 4 and 6 where the observation car was provided with an oil headlight.

Test No. 2. Observation of Colors of Home Signal at Distances Ranging from 300 to 5,000 Feet with Oil Headlight on Observation Car and on Opposing Electric Headlight 200 Feet in Front of Home Signal.

Under the conditions of this test the results were quite similar to those of test No. 1, with the exception that no phantom signals were noticed. One observer only interpreted the signal correctly at a distance of 3000 ft., and at 600 ft., practically all observations were correct.

The results of this test show that distances at which signals can be correctly interpreted are affected more by the character of the opposing headlight than by that of the headlight on the observation car, and further, that phantom signals are due to the reflected light from the unlighted roundels made noticeable by the great intensity of the electric headlight.

Test No. 3. Observation of Colors of Home Signal at Distances Ranging from 300 to 5,000 Feet with Electric Headlight on Observation Car and the Opposing Oil Headlight 200 Feet in Front of the Home Signal.

The correct aspect of the home signal was generally recognized in this test at the full distance of 5,000 ft. and identification was practically complete at 3000 ft. Here again it should be noted that a considerable number of phantom signals were recorded due to reflection, these appearing at distances ranging from 600 to 800 ft. The above results indicate that in case the locomotive engineer is called upon to read signals at the time he is meeting a train equipped with an electric headlight, the distance and therefore the time in which he must make his correct observation is much less than when the opposing headlight is of a less powerful type.

Test No. 4. Observation of Colors of Home Signal at Distances Ranging from 300 to 5,000 feet with Oil Headlight on Observation Car and the Opposing Oil Headlight 200 Feet in Front of the Home Signal.

Under the conditions of this test practically all the observers were able to read the signals correctly at the full distance of 5,000 ft. and identification was unanimous at 2,000 ft.

Test No. 5. Observation of Colors of Home Signals at Distances Ranging from 300 to 5000 Feet with Electric Headlight on Observation Car and no Opposing Headlight.

Practically complete identification of the home signals was made by all observers at the full distance of 5,000 ft. In spite of the fact that there was no light behind one of the green roundels during the test, several observers recorded a green signal at distances ranging from 400 to 800 ft.

Test No. 6. Observation of Colors of Home Signals at Distances Ranging from 300 to 5000 Feet with Oil Headlight on Observation Car and no Opposing Headlight.

This test represents the best condition for the reading of signals since they were all read correctly by all observers at 4,000 feet and no phantom signals due to reflection were observed.

Classification Signal Tests

Tests Nos. 7 to 10 inclusive were made to determine the distance at which the classification signals on the front of the approaching locomotive could be read with the two types of headlights. As the classification signals displayed on the front of the locomotive indicate either that a train is a special or that another train is following on the same schedule, it will be noted that the correct reading of these signals is of extreme importance. The procedure in all of these tests was as follows:

The observation car was run back several thousand feet and a long blast of the whistle sounded. An engine with an opposing electric headlight displaying classification signals located at the side of the smoke box was run on to the same track. Upon notice from the committee which prepared the classification signals, the observation car was moved forward slowly and first stopped at a distance of 400 ft. from the opposing locomotive. Additional stops were made at distances of 100 ft. until observations became unanimous in reading the classification signals.

Test No. 7. Classification Signal Test with Electric Headlight On Observation Car and Opposing Electric Headlight on Locomotive.

In this test both white and green classification signals were displayed. At 400 ft. only four observers saw the white light and at 300 ft. only eight could see it. None of the observers saw the green light at a distance of 200 ft., while nine of the eleven observers saw the white light at this distance. The above test indicates that the opposing electric headlight limits the distance in which the engineer can correctly observe the classification signals to a very small margin. The difficulty in observing the green signal was possibly due to the predominance of green rays in the headlight used. The spectrophotometric analysis of this light is shown in Table IX.

Test No. 8. Classification Signal Test with Electric Headlight on Observation Car and Opposing Oil Headlight on Locomotive.

The green and white classification signals displayed in this test were read correctly without difficulty by all observers at 400 ft., most of the observers having seen the signals at 800 ft. The ability to read classification signals correctly, therefore, is much greater with the oil headlight opposing than in the case of the more powerful electric headlight.

Test No. 9. Classification Signal Test with Oil Headlight on Observation Car and Opposing Oil Headlight on Locomotive.

The green and white classification signals were correctly identified by all observers at 600 ft. while some observers noted signals correctly at distances ranging from 1,200 to 2,200 ft. It is interesting to note from this test that with nothing more powerful opposing than an oil headlight, with an oil headlight on the observation car, the distance at which classification signals could be read was increased over that with an electric headlight on the observation car by about 50 per cent.

Test No. 10. Classification Signal Test with Oil Headlight on Observation Car and Opposing Electric Headlight on Locomotive.

Two white classification signals were displayed and were seen correctly by all observers at 300 ft., while some observers saw them correctly at distances ranging from 600 to 800 ft. It

should be noted from this test that the inability to distinguish correctly the green signal in Test No. 7 is not due to its position upon the locomotive, but rather to its color, since the two white signals in this test were distinguished at the same distance.

Obstruction Tests

It has been argued that more powerful headlights for locomotives, by increasing the distances at which obstructions may be seen on the track, may prevent the occurrence of accidents. The following tests were made to determine the exact distance at which various objects on the track in advance of the locomotive could be seen and identified. It should be noted that in these tests the observers were on the lookout for some obstruction and observations were made at times when the car was at a standstill, both of which conditions were obviously more favorable to the correct detection of objects on the track than in ordinary railroad practice. The procedure in all of these obstruction tests was as follows:

The observation car was run back a distance of 2,000 ft. and the usual signal given with the whistle. Different objects were then placed upon the track in the various tests, the approximate localities of the obstructions being known to the observers, who, however, had no knowledge of the kind of obstructions which were to be used. When signalled by the committee which had the preparation of the obstacles in charge, the observation car was moved slowly forward and stopped at regular intervals. Independent records were made at each stop of whatever obstruction was noted by the observer. Note was also made of the distance at which the obstruction could be identified. An electric headlight was used on the observation car throughout these tests.

Test No. 11.

A speeder was placed on the track for this test. Comparison of the records shows that this was first noticed by about one-half of the observers at a distance of 700 ft. and by the remainder at 500 ft. It was not fully identified, however, until the car was within 300 ft. of the obstruction.

Test No. 12.

A car was backed on a siding so as not to be entirely clear of the main track. The majority of the observers did not

notice this obstruction until the observation car was within about 900 ft. of it. Those who were not railroad men, or at least familiar with railroad practice, did not recognize this car as an obstruction, so that the test was not conclusive.

Test No. 13.

Two sacks stuffed with straw about the size of a man's body were placed between the rails and remained unidentified by all but two observers until the car was within 250 ft. of the obstruction.

Test No. 14.

Two coal cars were backed on the main track for the final test. This obstruction was noticed by practically all observers at a distance of 1,300 ft. but was not fully identified until the observation car was within 900 ft. of the obstruction.

Conclusions

The following general conclusions seem warranted from the results of the above road tests:

1. That a powerful headlight on a locomotive has one marked disadvantage, namely, that it causes reflections from glass roundels and lenses, thereby producing false or phantom signals. It seems likely that these are partly due to the intensity and partly to the spectral composition of the light.

2. That a powerful opposing headlight adjacent to block signals so obscures the latter as to make it difficult to read them correctly at distances exceeding 1,000 ft.

3. That an opposing oil headlight of ordinary intensity allows such signals to be read correctly at 4,000 ft. or less.

4. That even with no opposing headlight, the distance in which the signal can be read correctly is slightly reduced by the use of a powerful headlight.

5. That a more powerful headlight on an approaching engine obscures the classification signals on that engine to a marked degree. This is particularly true of green signals in the glare of a powerful headlight whose spectral intensity is high in green.

6. That an opposing oil headlight of ordinary intensity allows either white or green signals to be read at a distance of 400 ft. or even more.

7. That obstructions on the track cannot ordinarily be seen with a powerful electric headlight at a sufficient distance to

prevent accidents, since a train travelling at a high rate of speed cannot be stopped in the distance at which obstacles sufficiently large to cause a wreck were first detected.

Group II—Laboratory Tests

This group of laboratory tests consists of four separate series made on seven different lamps of various types. The lamps are referred to in this paper by number and may be briefly described as follows:

No. 1. Luminous arc, upper electrode copper, lower electrode presumably magnetite composition.

No. 2. Carbon arc, carbons inclined 45 deg. to the horizontal.

No. 3. Luminous arc, similar to No. 1.

No. 4. Electric arc, upper electrode carbon, lower electrode copper.

No. 5. Kerosene oil lamp.

No. 6. Acetylene lamp.

No. 7. Luminous arc, same as No. 1, but instead of being fitted with a reflector, supplied with a lens.

Each of the above headlights was fitted with a reflector supposedly parabolic in shape, except No. 7 which, as before noted, was arranged with a lens before the lamp. The reflectors on Nos. 4, 5 and 6 were polished silver, and those on Nos. 1, 2 and 3 seemed to be polished aluminum.

Four series of tests were made upon these lamps as follows:

Test No. 15. A determination of the illumination produced by the headlight at a fixed point in the axis of the reflector.

Test No. 16. A determination of the total light flux generated by the lamp.

Test No. 17. A determination of the illumination produced along a course of 1300 ft. in front of the headlight.

Test No. 18. A spectro-photometric analysis of the light from each lamp.

In addition to the above, tests were made upon signal roundels taken from service.

Test No. 19. A spectrophotometric analysis of the light reflected from roundels.

Test No. 20. A determination of the reflection coefficients of roundels with and without signal lamps.

It is not necessary to point out in this paper the greater difficulties in obtaining exact results in photometric and especially in spectrophotometric analyses of the light furnished by the

electric arc lamp over those encountered in the comparison of most other illuminants. This is particularly true in the case of the electric arc headlights where not only the fluctuations of the arc itself are the direct cause of sudden variations in intensity, but also because of the fact that the arc may at times get out of the focus of the reflector and thus greatly multiply the variation in intensity of the reflected light. It should be pointed out, therefore, that the accuracy is probably greater in the following tests made with oil and acetylene headlights than in the case of the electric arc headlights, although every precaution was taken in all tests to obtain constant reading conditions. The results recorded in the following pages represent the average of a number of readings taken by several observers.

Test No. 15. *A Determination of the Illumination Produced by the Headlight at a Fixed Point in the Axis of the Reflector.*

In this series of tests the headlights were mounted in a dark room arranged for photometric purposes in such a manner that the axis of the reflector passed through the position of a Lummer-Brodhun type of sight box located at the opposite end of the room at the fixed distance of 25.7 feet from the position of the lamp. To balance the illumination of the arc, on the opposite side of the photometer screen, an incandescent lamp of appropriate intensity maintained at a definite voltage was arranged to be controlled by the observer at the sight box. Also, under the control of the observer and moving with the lamp was an electromagnetically operated punch enabling him to record on a sheet of paper upon a drum the position of the lamp corresponding to a photometric balance between the headlight and the comparison lamp. This device was described by Matthews in a paper before the A.I.E.E. in 1901.* By its means a large number of independent observations corresponding to each condition were easily taken and thus a proper average obtained. With the hope of reducing the large number of possible errors in photometering and electric arc, the substitution method was used throughout, *i.e.*, the comparison lamp while on the bar in working position was frequently compared with a standardized lamp put in position on the headlight side of the sight box.

On account of the extremely high illumination produced by the headlight, it was found necessary to reduce the intensity at

*"An Improved Apparatus for Arc Light Photometry," Chas. P. Mathews, TRANSACTIONS, A.I.E.E., Vol. XVIII, p. 677.

the sight box in most cases by the use of the well known rotating sectored screen. The only exception to this was with the oil headlight. The constant of the rotating screen was carefully determined and the value checked.

The headlights were all operated as nearly as possible under conditions as specified by the manufacturers. Thus, lamps Nos. 1, 2, 3 and 7 were operated in series with their respective resistances on a pressure of 550 volts, lamp No. 4 with a constant current of 28 amperes, No. 6 with a gas pressure from a tank supplied by the manufacturers, and No. 5 with as high a flame height as could be maintained without the lamp smoking.

From the theory of the reflector, it was decided that the light probably did not follow the law of inverse squares, and since the law of the illumination was to us unknown, it was decided not to attempt to express the intensity of the headlight, but rather the intensity of the illumination produced by it. It was hoped that time would permit the inclusion in this paper of the results of tests planned and in progress for the determination of the law or laws of the variation of the light from these reflectors, but it was found impossible to get these tests finished in time.

The results of test No. 15 are found in Table I expressed in candle-feet of illumination. Considerable fluctuation of the intensity was noted during the test on each lamp and the average value given in the table is the average of from twenty to eighty readings. It was thought that the range of variation for any one lamp might be of interest and the maximum and minimum values of the illumination are accordingly given in the table together with the percentage variation above and below the average.

In column 19 of the same table is found the ratio of the illumination of each lamp to that of the oil lamp, which on account of longer and more common use was taken as a standard for the others. It is of interest to note that the highest illumination was produced by No. 7, and that the illumination from this lamp is a little more than twice as great as the illumination from No. 1, the only difference between the two lamps being that No. 7 is equipped with a lens and No. 1 with a reflector. It is also to be noted that the ratios of the illumination produced by the arc headlights to that of the oil light are of the same order, varying from 23.5 to 49. It is not to be supposed, however, that these ratios would be the same at all distances in front of the headlights, in fact, the results of test No. 17 show quite the con-

trary. This likely is due to the fact that the law of variation of the intensity of the light is, or may be different for each reflector.

Test No. 16. A Determination of the Total Flux Generated by the Lamp.

To make this test, the reflector and all unnecessary equipment was removed from the headlight which was then hung in a circle of mirrors constituting a portion of the mirror photometer described by Matthews in the paper previously cited. These mirrors were located 15 deg. apart enabling the intensity of the light from the lamp to be determined at angular steps of 15 deg. above and below the horizontal. The coefficients of reflection of the mirrors had been previously determined.

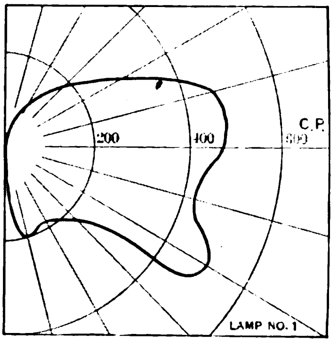


FIG. 1—Distribution of lamp No. 1

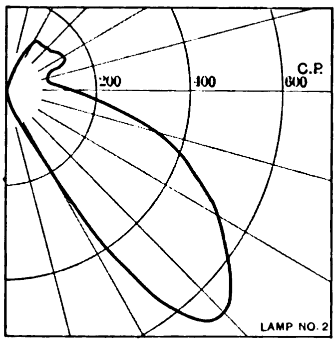


FIG. 2—Distribution of lamp No. 2

The sight box of the photometer was located at the same point as in test No. 15, and the settings were taken in the same manner, with the lamp operating normally, and with all the mirrors covered except those corresponding to the particular angle in which the intensity was being determined. The light from the uncovered mirrors was reflected directly to the photometric screen in the sight box. The intensity determined is from an average of from 20 to 50 independent settings of the photometer taken during a time varying from 5 to 10 minutes. It is believed, therefore, that the results thus obtained represent the average condition of operation.

From these intensities a distribution curve of light from each lamp was plotted and the Kennelly method for determining the total light flux in spherical candles was applied. This method

is described by its originator in the Transactions of the Illuminating Engineering Society. In using this method the distribution curve was divided into 15 deg. zones which, it was thought, would insure the accuracy of the determination to a point equal to that ordinarily obtained in photometric work. This method of determining the total light flux from the distribution curve was preferred to the method of obtaining it by a single setting on account of the fact that, in some of the lamps, a shadow was cast at the extreme angles above and below the horizontal by a part of the frame work supporting the arc mechanism. In the method used, the error which would have been introduced by using the single setting method was reduced by assuming such values of intensity at these angles as seemed likely from the trend of the distribution curve. It is not claimed that this can

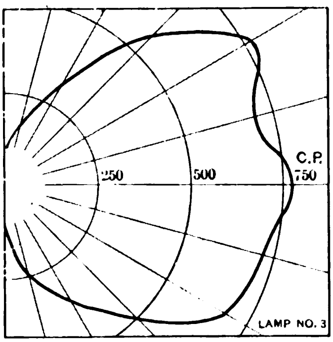


FIG. 3—Distribution of lamp No. 3

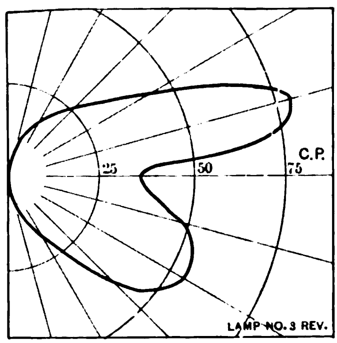


FIG. 4—Distribution of lamp No. 3 (reversed)

give results of extreme accuracy. It is true, however, that a small variation in the intensities in these directions has little effect upon the total light flux as determined.

The distribution curve for No. 2 could not be obtained with the arc in its normal position because of the fact that this position is with the carbons at an angle of 45 degrees from the vertical. On that account, a distribution curve taken in the vertical plane cannot be used to determine the mean spherical candle power. To obtain a distribution curve for this lamp, it was mounted so that its carbons hung in a vertical plane and the distribution curve taken as in the other types of lamp. It was not considered, however, that this curve would coincide with the curve that would obtain were the lamp hanging in its normal position, because of the fact that the regulating mechanism has its center

of gravity disturbed by this change resulting in a length of arc different from that in normal operation. The value of the mean spherical candle power obtained from this curve is found in Table 1 Column 14. An attempt to correct for this abnormal condition was made by taking the intensity of the lamp when suspended normally in a direction corresponding to an angle of 37½ deg. from the horizontal with the carbons in a vertical position. The value thus obtained was considerably larger, than the intensity at the same angle with the lamp in its abnormal position as in the first case, the ratio between the two being 1.35. The intensities taken in the first determination were then multiplied by this ratio and the mean spherical candle power determined from these corrected values. Naturally, this is a considerably higher value than that obtained at first. It seems

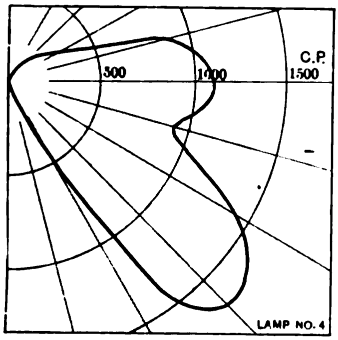


FIG. 5—Distribution of lamp No 4

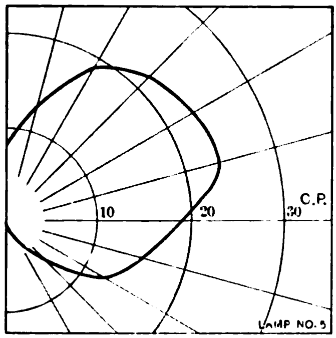


FIG. 6—Distribution of lamp No. 5

likely that the value thus obtained is more nearly correct. The values of these light fluxes are found in Table I column 14, and in column 15 are found values of the illumination at the photometer sight box corresponding to the total flux found in column 14. These values of illumination were obtained by dividing the light flux for a given lamp by the square of its distance from the photometric screen. Thus for lamp No. 1, 790 mean spherical c.p. $\div (25.7)^2 = 1.197$. This may be called the hypothetical value of the illumination were the reflector absent. To obtain an idea of the effectiveness of the reflector the actual values of illumination obtained at the fixed point with reflector on the lamp were divided by the hypothetical values in column 15, giving results shown in column 22. The value thus obtained may be called the "Multiplying Factor of the Reflector". It

will be observed that this factor is not the same for all reflectors, varying from 58.7 for No. 4 to 241 for No. 2.

From the exceedingly high value of this factor for No. 2 the comparatively low total flux of this lamp and the peculiar distribution of light from a carbon arc, it seems probable that the value of this factor is a function of the distribution of the light about the source. In this particular case the inclination of the carbons from the vertical, causes the most intense ray to fall directly in the vertex of the reflector. In no other case does this occur. In the case of No. 4 which has a distribution curve very similar to No. 2, since the electrodes are vertical, the strongest ray, *i.e.*, 45 deg. below the horizontal, does not strike the vertex of the reflector. It may be noted in this connection that the multiplying factor of this reflector is the lowest of any. An explanation of this condition may be found in the fact that the proportion of total light flux falling in the vertex of the reflector is smaller for this lamp, as shown by the curves and the values in Table I, than for any other.

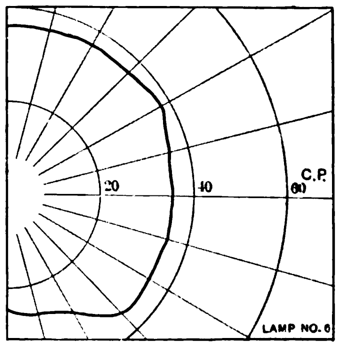


Fig. 7—Distribution of lamp No. 6

The foregoing is to be understood only as a possible explanation of the variation in what has been called the multiplying factor of reflectors which were clean and in apparently good working condition.

Test No. 17. A Determination of the Illumination Produced along a Course of 1300 Feet in Front of the Headlight.

The nature of this test, which was conducted on moonless nights, is much the same as test No. 15, differing from it principally in the method employed. The attempt was made to duplicate as nearly as possible conditions as to position of headlight and illumination produced thereby as they would occur in practice.

In pursuance of this idea, a tower platform 15 ft. 6 in. high was built out of doors at one end of a course 1,300 ft. in length. The reason for selecting this height was that on the locomotive used in the road tests the headlight was mounted 11 ft. 6 in. above the track. The sight box of the portable photometer was four ft.

high and by placing the headlight on the platform at a height of 15 ft. 6 in., it was possible to determine the illumination as it would occur on the track. The headlights designed for electric traction use were mounted at a height above the photometer level corresponding to that at which they are normally carried on the car.

The photometer used was a Lummer-Brodhun mounted on a tripod. For the purpose of excluding stray light it was fitted with a hood consisting of two tubes of sheet iron 20 in. long by two inches in diameter, blackened within with lamp black. These tubes were attached to the sight box, one on each side entirely covering the opening so that no light could fall upon either side of the screen which did not pass through the tubes.

For comparison, standardized incandescent lamps were used, which during the tests were maintained at a voltage corresponding to their previously determined intensity by means of a rheostat. Power for these comparison lamps was obtained from a storage battery through a line erected parallel with and adjacent to the course, and having sockets connected in at every 100 ft.

The course, which was practically level, was laid off with chain and transit, and for the first 500 ft. stations were established every 50 ft., and after that, every 100 ft. The method of making the test was as follows:

With the headlight in operation and directed along the course in such a manner that the nearer edge of the reflected beam first touched the ground at about 400 ft. in front of the lamp, the photometer was set up over each station in turn, with its tube directed toward the headlight. The comparison lamp, held by one person, who also held at the lamp one end of a 100-ft. steel tape, was moved at the will of the observer at the sight box until a photometric balance was obtained. Several observations were made at each station by different observers, which on account of fluctuations in the source of light, at times varied considerably. The values of illumination presented in Table II represent the average of these readings.

The variation of headlight illumination with distance as determined in this test is clearly shown in Table II as well as in Figs. 8 and 9 whose curves are plotted from the data in the above table. Fig. 8 is plotted to a larger scale and includes headlights numbered 2, 4 and 7 which showed the greatest intensities. It should be noted that there is a marked similarity in the general form of these three curves and the relative intensities of the

illumination in spite of the fact that they are taken from different types of headlights. In Fig. 9, the intensities of the remainder of the headlights are shown together with a portion of the curves reproduced from Fig. 8 to smaller scale. From this one figure, therefore, a comparison can be made of the intensities of all types and makes of headlights tested. The contrast between curve No. 5 representing the common type of kerosene oil locomotive headlight and the other curves, representing more powerful types, is very marked, and it is interesting to note that at the maximum distance of 1,300 ft. considered in

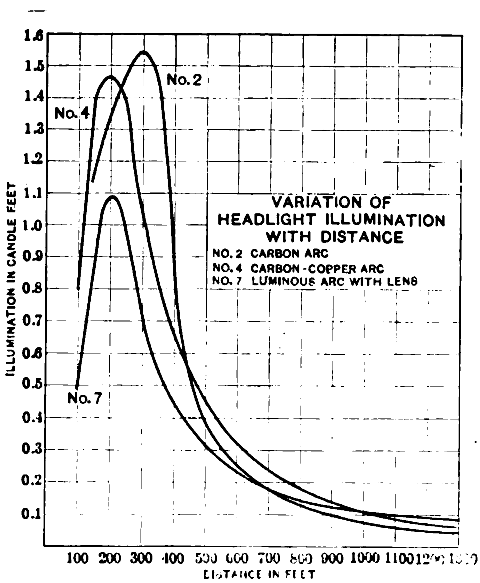


Fig. 8

these tests, three headlights, numbered 2, 4 and 7 gave an illumination considerably above the maximum possible at any distance with the kerosene oil headlight.

It will be noted from the curves, Fig. 8 and 9, that in nearly all cases the illumination starting at some value near the lamp increased to a maximum at from 200 to 400 ft. from the lamp, and again decreased as the distance was increased.

That the point of maximum intensity is at some distance from the lamp may be accounted for from the fact that at distances less than that at which the maximum occurs, the illumination is largely due to the direct and not the reflected rays. At points

which are illuminated by both direct and reflected rays, the illumination is naturally higher.

Test No. 18. A Spectrophotometric Analysis of the Light from Each Lamp.

In order to determine the relative intensities of the various primary colors in the direct rays of the several types of head-

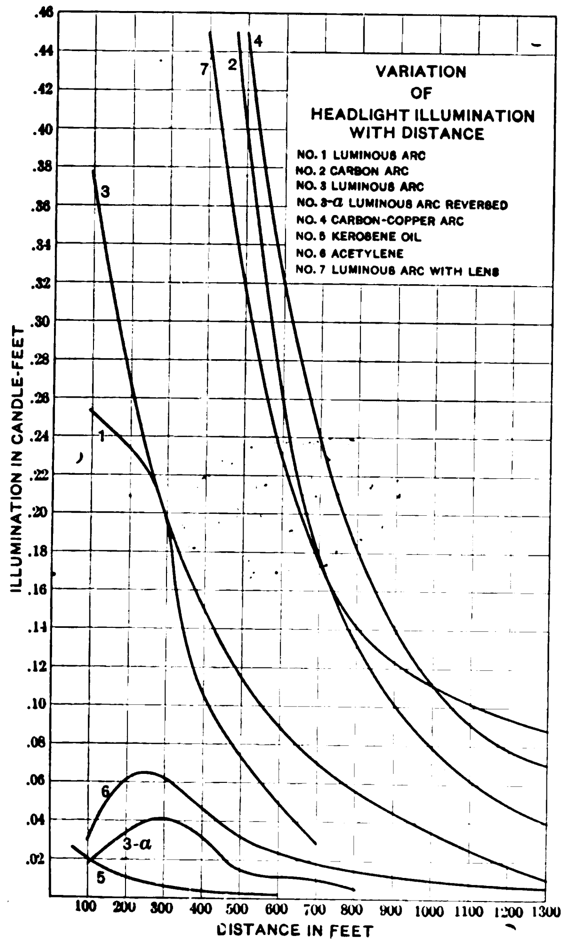


Fig. 9

lights, a Martens-Koenig spectrophotometer was used. With this instrument the intensity of the light in the yellow portion of the spectrum, corresponding to the wave length of sodium light, (0.0005890 cm.) was balanced against that in the same portion of the spectrum furnished by a carbon incandescent lamp

operating at constant rated voltage. The ratio of intensities in other portions of the spectrum was then obtained by turning the Nichol prism of the instrument through a measurable angle, thus polarizing a portion of the light from one of the sources. This ratio is then proportional to the square of the tangent of the angle from the point of complete polarization through which the Nichol prism has been turned to obtain a balance. The carbon incandescent lamp which was used in this case as a secondary standard was later compared with daylight reflected from the sky. Readings of the spectrophotometer were made only when the intensity of the arc was shown by the Lummer-Brodhun screen to be the same as when balanced at the wave length of sodium.

In the following tables, numbered from III to XII inclusive, together with Figs. 11 to 14 inclusive, which include curves

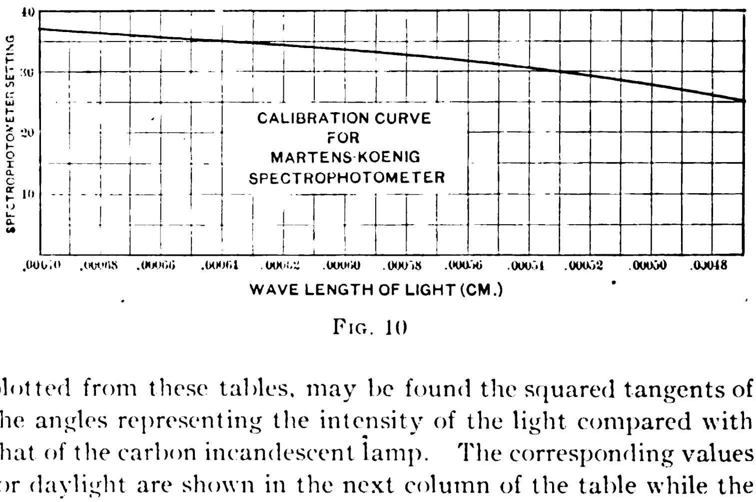
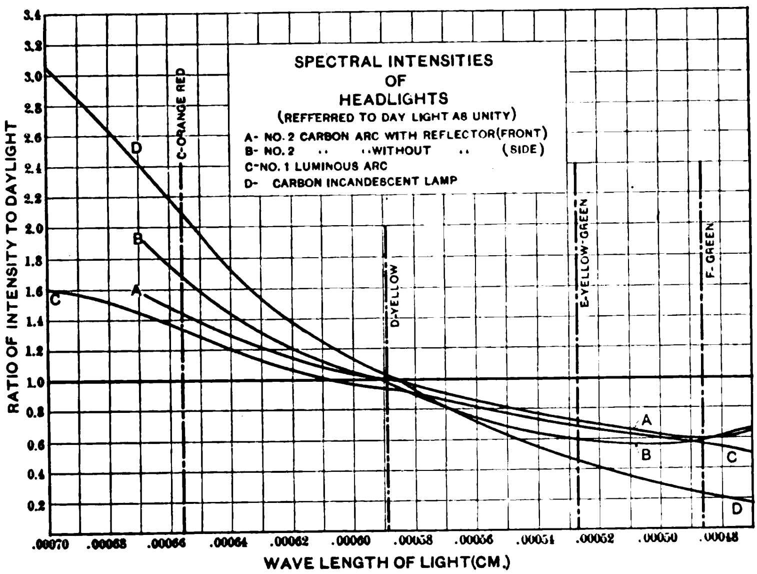


FIG. 10

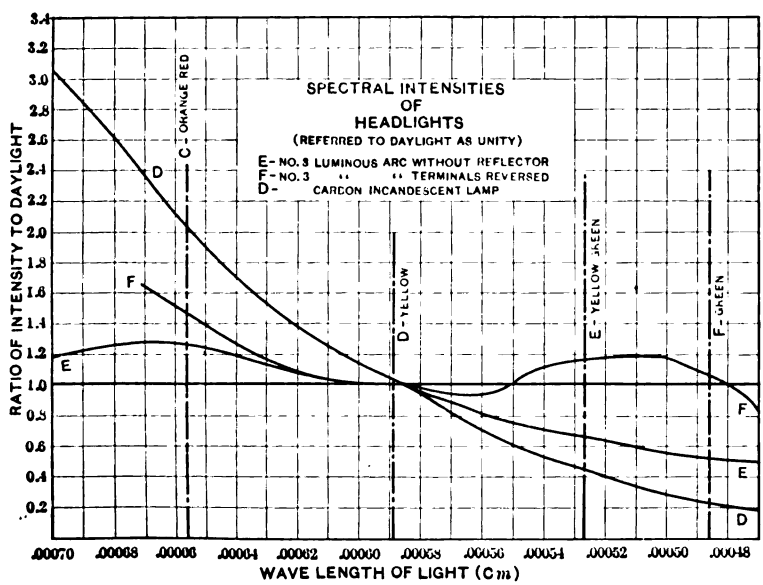
plotted from these tables, may be found the squared tangents of the angles representing the intensity of the light compared with that of the carbon incandescent lamp. The corresponding values for daylight are shown in the next column of the table while the ratios of the intensity of the particular light to that of daylight are shown in the last column. These latter values are plotted as ordinates in the following curves while the corresponding wave lengths of light listed in the second column of the tables are plotted as abscissæ.

In further explanation of the curves given in Fig. 11 to 15 inclusive, it should be noted that in each figure curve *D* represents the ratio of intensity of the carbon incandescent lamp to daylight. It is possible, therefore, to compare the spectral intensities of the lights being considered, with daylight not only, but also with the incandescent secondary standard lamp.



SPECTRAL INTENSITIES
OF
HEADLIGHTS
(REFFERRED TO DAY LIGHT AS UNITY)
A- NO. 2 CARBON ARC WITH REFLECTOR(FRONT)
B- NO. 2 " "WITHOUT " (SIDE)
C-NO. 1 LUMINOUS ARC
D- CARBON INCANDESCENT LAMP
C-ORANGE RED
D-YELLOW
E-YELLOW-GREEN
F. GREEN
RATIO OF INTENSITY TO DAYLIGHT
WAVE LENGTH OF LIGHT(CM.)

FIG. 11



SPECTRAL INTENSITIES
OF
HEADLIGHTS
(REFERRED TO DAYLIGHT AS UNITY)
E- NO. 3 LUMINOUS ARC WITHOUT REFLECTOR
F- NO. 3 " " TERMINALS REVERSED
D- CARBON INCANDESCENT LAMP
C - ORANGE RED
D - YELLOW
F - GREEN
RATIO OF INTENSITY TO DAYLIGHT
WAVE LENGTH OF LIGHT (Cm)

FIG. 12

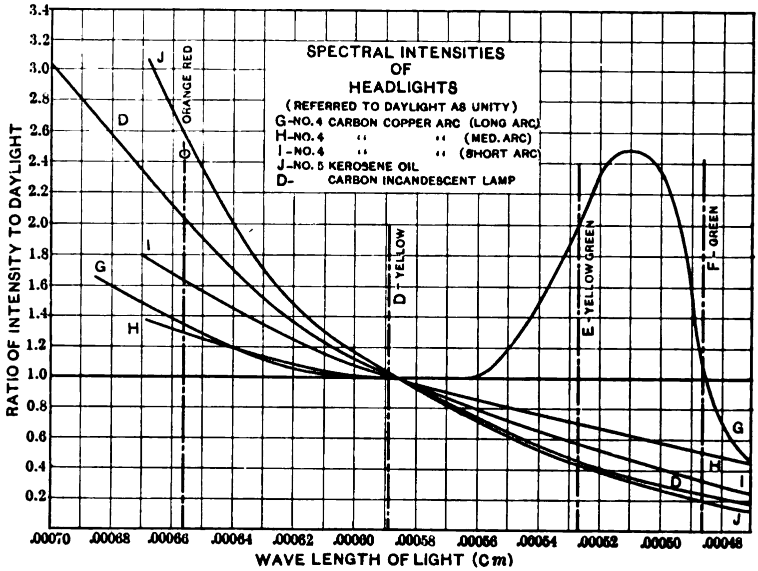

SPECTRAL INTENSITIES
OF
HEADLIGHTS
(REFERRED TO DAYLIGHT AS UNITY)
G-NO. 4 CARBON COPPER ARC (LONG ARC)
H-NO. 4 " " (MED. ARC)
I-NO. 4 " " (SHORT ARC)
J-NO. 5 KEROSENE OIL
D- CARBON INCANDESCENT LAMP
RATIO OF INTENSITY TO DAYLIGHT
WAVE LENGTH OF LIGHT (Cm)
C- ORANGE RED
D-YELLOW
E-YELLOW GREEN
F-GREEN

FIG. 13

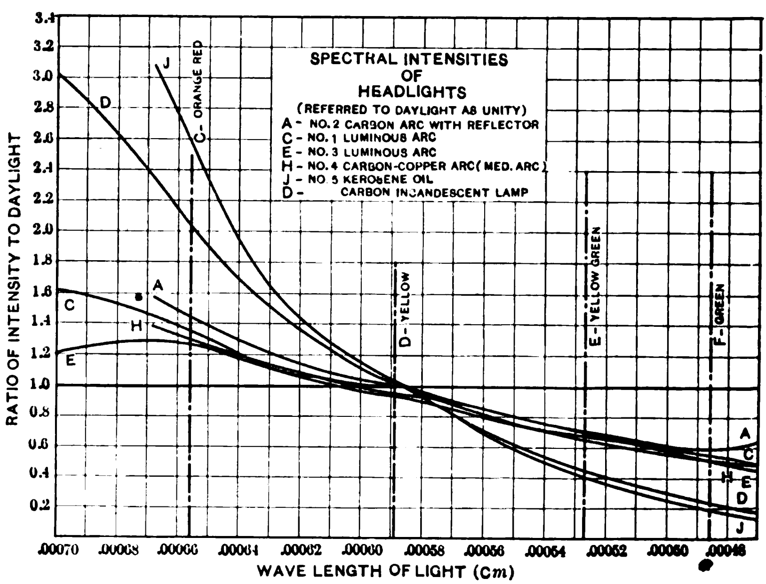

SPECTRAL INTENSITIES
OF
HEADLIGHTS
(REFERRED TO DAYLIGHT AS UNITY)
A- NO. 2 CARBON ARC WITH REFLECTOR
C- NO. 1 LUMINOUS ARC
E- NO. 3 LUMINOUS ARC
H- NO. 4 CARBON-COPPER ARC (MED. ARC)
J- NO. 5 KEROSENE OIL
D- CARBON INCANDESCENT LAMP
RATIO OF INTENSITY TO DAYLIGHT
WAVE LENGTH OF LIGHT (Cm)
C- ORANGE RED
D-YELLOW
E-YELLOW GREEN
F-GREEN

FIG. 14

By referring to Fig. 11 it will be seen that the intensity of the luminous arc headlight in the various portions of the spectrum is not materially different from that of the carbon arc, the former being slightly lower in the red than the latter. All types of headlights, with the exception of the kerosene oil shown

TABLE III. SPECTRAL INTENSITIES OF CARBON INCANDESCENT LAMP REFERRED TO DAYLIGHT

Setting	Wave length (cm.)	Average reading	Cotangent squared
37	0.000700	29.8	3.04
36	0.000668	33.1	2.36
35	0.000640	37.4	1.71
34	0.000812	41.7	1.26
33	0.000586	45.1	1.00
32	0.000564	49.0	0.758
31	0.000548	52.0	0.610
30	0.000532	55.0	0.494
29	0.000516	58.0	0.393
28	0.000502	60.5	0.322
27	0.000490	63.0	0.260
26	0.000480	65.0	0.218
25	0.000470	67.0	0.182

TABLE IV. SPECTRAL INTENSITIES OF HEADLIGHT NO. 1

Setting	Wave length (cm.)	Average reading	Tangent squared	Tangent squared daylight	Ratio intensity to daylight
37	0.000700	36.1	0.530	0.329	1.61
36	0.000668	38.1	0.613	0.425	1.44
35	0.000640	40.1	0.710	0.585	1.21
34	0.000812	42.1	0.815	0.795	1.02
33	0.000586	44.1	0.935	1.00	0.935
32	0.000564	46.1	1.075	1.32	0.815
31	0.000548	48.1	1.240	1.64	0.755
30	0.000532	50.1	1.42	2.03	0.700
29	0.000516	52.1	1.65	2.55	0.646
28	0.000502	54.1	1.90	3.11	0.610
27	0.000490	56.0	2.21	3.85	0.574
26	0.000480	57.8	2.51	4.60	0.545
25	0.000470	58.9	2.74	5.51	0.497
24	0.000460	59.8	2.96		
23	0.000450	60.0	3.22		

in Fig. 13, have less intensity in the orange and red and greater intensity in the green and violet than the incandescent lamp, as would be expected. Fig. 12 shows an interesting feature in connection with the luminous arc headlight with terminals reversed which provision is made in some cases for temporarily

reducing the intensity of headlights. Such a reversal introduces a relatively high intensity in the green portion of the spectrum probably due to the burning away of the copper electrode. A similar but more marked effect is shown in Fig. 13 in connection with an arc headlight of another type using a lower electrode of copper, with which it was found that, if a long arc were permitted to form, very high intensities in the green portion of the spectrum were introduced, probably due to the cause mentioned above. From the green appearance of the light given at times by this electric headlight, which was used in the road tests,

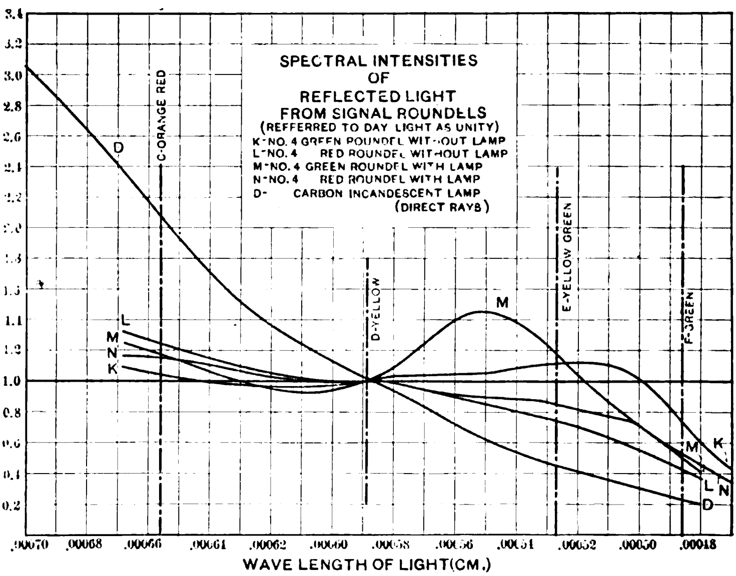


FIG. 15

it is quite probable that this condition sometimes obtains in practice and it is believed that the possibility of obtaining green phantom signals is increased by this fact.

Test No. 19. A spectrophotometric Analysis of the Light Reflected from Roundels.

In this test the same spectrophotometer was used and the method of procedure was the same as in test No. 18, with the exception that the light analyzed was first reflected from signal roundels. Headlight No. 4, which was used in the road tests,

furnished the light for this analysis. Tables XIII to XVI inclusive show the results obtained in this test which are plotted in Fig. 15. The point of particular significance, in explanation of the phantom signals found in the road tests, is the fact that the

TABLE V. SPECTRAL INTENSITIES OF HEADLIGHT NO. 2 FRONT WITH REFLECTOR

Setting	Wave length (cm.)	Average reading	Tangent squared	Tangent squared daylight	Ratio intensity to daylight
36	0.000668	39.2	0.666	0.425	1.57
35	0.000640	41.1	0.760	0.585	1.30
34	0.000812	43.0	0.870	0.795	1.09
33	0.000586	45.0	1.000	1.00	1.00
32	0.000564	47.0	1.142	1.32	0.865
31	0.000548	49.0	1.320	1.64	0.805
30	0.000532	50.8	1.50	2.03	0.740
29	0.000516	52.9	1.745	2.55	0.685
28	0.000502	54.5	1.960	3.11	0.630
27	0.000490	56.7	2.31	3.85	0.600
26	0.000480	59.0	2.76	4.60	0.600
25	0.000470	62.0	3.54	5.51	0.641
24	0.000460	66.0	5.05	—	—
23	0.000450	71.1	8.50	—	—

TABLE VI. SPECTRAL INTENSITIES OF HEADLIGHT NO. 2 TURNED SIDEWISE NO REFLECTOR

Setting	Wave length (cm.)	Average reading	Tangent squared	Tangent squared daylight	Ratio intensity to daylight
36	0.000668	42.0	0.810	0.425	1.91
35	0.000640	42.6	0.840	0.585	1.44
34	0.000812	43.5	0.900	0.795	1.13
33	0.000586	44.2	0.944	1.00	0.944
32	0.000564	45.3	1.020	1.32	0.773
31	0.000548	46.5	1.11	1.64	0.677
30	0.000532	48.4	1.26	2.03	0.620
29	0.000516	50.5	1.47	2.55	0.576
28	0.000502	53.0	1.75	3.11	0.563
27	0.000490	56.0	2.20	3.85	0.570
26	0.000480	59.3	2.83	4.60	0.615
25	0.000470	62.0	3.53	5.51	0.640
24	0.000460	63.9	4.15	—	—
23	0.000450	64.6	4.42	—	—

intensities in the green portion of the spectrum of light reflected from green roundels are much greater than those reflected from red roundels. It is further noted that the effect of placing an unlighted signal lamp back of the green roundel, as is usually

TABLE VII. SPECTRAL INTENSITIES OF HEADLIGHT NO. 3

Setting	Wave length (cm.)	Average reading	Tangent squared	Tangent squared daylight	Ratio intensity to daylight
37	0.000700	32.0	0.390	0.329	1.19
36	0.000668	36.3	0.540	0.425	1.27
35	0.000640	39.8	0.691	0.585	1.18
34	0.000812	42.4	0.830	0.795	1.04
33	0.000586	44.8	0.985	1.00	0.985
32	0.000564	46.4	1.10	1.32	0.834
31	0.000548	48.0	1.23	1.64	0.750
30	0.000532	49.9	1.40	2.03	0.690
29	0.000516	51.5	1.57	2.55	0.616
28	0.000502	53.2	1.78	3.11	0.572
27	0.000490	55.0	2.03	3.85	0.527
26	0.000480	56.9	2.35	4.60	0.510
25	0.000470	58.7	2.70	5.51	0.490
24	0.000460	60.3	3.07	—	—
23	0.000450	62.0	3.53	—	—

TABLE VIII. SPECTRAL INTENSITIES OF HEADLIGHT NO. 3 TERMINALS REVERSED

Setting	Wave length (cm.)	Average reading	Tangent squared	Tangent squared daylight	Ratio intensity to daylight
36	0.000668	39.9	0.836	0.425	1.65
35	0.000640	41.0	0.869	0.585	1.28
34	0.000812	42.5	0.916	0.795	1.055
33	0.000586	45.0	1.00	1.00	1.00
32	0.000564	48.3	1.122	1.32	0.955
31	0.000548	53.0	1.327	1.64	1.068
30	0.000532	57.0	1.540	2.03	1.16
29	0.000516	60.0	1.732	2.55	1.175
28	0.000502	62.5	1.921	3.11	1.185
27	0.000490	64.0	2.050	3.85	1.09
26	0.000480	65.0	2.144	4.60	1.00
25	0.000470	65.0	2.144	5.51	0.835
24	0.000460	64.5	2.097	—	—

TABLE IX. SPECTRAL INTENSITIES OF HEADLIGHT NO. 4 MEDIUM ARC

Setting	Wave length (cm.)	Average reading	Tangent squared	Tangent squared daylight	Ratio intensity to daylight
36	0.000668	37.4	0.765	0.425	1.375
35	0.000640	40.0	0.839	0.585	1.20
34	0.000812	42.3	0.910	0.795	1.042
33	0.000586	44.8	0.993	1.00	1.985
32	0.000564	46.9	1.069	1.32	0.864
31	0.000548	49.0	1.150	1.64	0.804
30	0.000532	50.7	1.222	2.03	0.734
29	0.000516	52.4	1.299	2.55	0.658
28	0.000502	54.0	1.376	3.11	0.608
27	0.000490	55.4	1.450	3.85	0.545
26	0.000480	56.8	1.528	4.60	0.504
25	0.000470	57.8	1.588	5.51	0.455
24	0.000460	58.5	1.632	—	—

the case in practice, apparently increases, to a very marked extent, the intensity in the yellow-green portion of the spectrum of the reflected light.

Test No. 20. A Laboratory Determination of the Reflection Coefficients of Roundels with and without Signal Lamps.

After it was found in the previous test that the placing of a signal lamp back of a green roundel greatly increased the intensity of the reflected light in the yellow-green portion of the spectrum, it seemed worth while to determine the reflection coefficients of both green and red roundels with and without signal lamps placed directly behind them in the position which

TABLE X. SPECTRAL INTENSITIES OF HEADLIGHT NO. 4. LONG ARC

Setting	Wave length (cm.)	Average reading	Tangent squared	Tangent squared daylight	Ratio intensity to daylight
37	0.000700	37.5	0.588	0.329	1.79
36	0.000668	38.3	0.623	0.425	1.47
35	0.000640	39.9	0.700	0.585	1.20
34	0.000812	42.0	0.810	0.795	1.02
33	0.000586	45.0	1.00	1.00	1.00
32	0.000564	49.0	1.32	1.32	1.00
31	0.000548	55.2	2.06	1.64	1.26
30	0.000532	62.3	3.61	2.03	1.78
29	0.000516	68.2	6.25	2.55	2.46
28	0.000502	70.0	7.51	3.11	2.42
27	0.000490	68.0	6.10	3.85	1.58
26	0.000480	61.4	3.35	4.60	0.728
25	0.000470	58.1	2.57	5.51	0.465
24	0.000460	58.2	2.60	—	—

they occupy in practice. These results are clearly shown in Table XVII from which it will be noted that the reflection coefficients of red roundels are slightly greater than those of green roundels but that in both cases, the coefficients are greater when the roundels are mounted in front of signal lamps. It seems probable that the increase in this coefficient is due to the presence of the lens of the signal lamp.

In conclusion, it may be well to call attention to other tests not formally listed herein, which were made in connection with the laboratory tests to reproduce, if possible, the phantom signals noticed in the road tests. Headlight No. 4 was mounted upon the platform described in test No. 17, and red and green signal roundels with and without signal lamps were placed in a position

corresponding to that of the home signal. Although the signal lamps located behind the roundels being tested were not lighted, yellowish green reflections were obtained from the roundels which were quite as brilliant as other signals placed near by for

TABLE XI. SPECTRAL INTENSITIES OF HEADLIGHT NO. 4. SHORT ARC

Setting	Wave length (cm.)	Average reading	Tangent squared	Tangent squared daylight	Ratio intensity to daylight
36	0.000668	41.1	0.760	0.425	1.79
35	0.000640	42.6	0.841	0.585	1.44
34	0.000812	43.9	0.921	0.795	1.16
33	0.000586	45.0	1.000	1.00	1.00
32	0.000564	46.1	1.075	1.32	0.815
31	0.000548	47.1	1.155	1.64	0.705
30	0.000532	48.0	1.230	2.03	0.606
29	0.000516	48.9	1.305	2.55	0.512
28	0.000502	49.2	1.335	3.11	0.429
27	0.000490	49.6	1.380	3.85	0.358
26	0.000480	49.8	1.400	4.60	0.304
25	0.000470	49.95	1.42	5.51	0.258
24	0.000460	50.0	1.42	—	—
23	0.000450	50.0	1.42	—	—

TABLE XII. SPECTRAL INTENSITIES OF HEADLIGHT NO. 5

Setting	Wave length (cm.)	Average reading	Tangent squared	Tangent squared daylight	Ratio intensity to daylight
37	0.000700	52.1	1.641	0.329	4.99
36	0.000668	48.9	1.31	0.425	3.08
35	0.000640	46.9	1.14	0.585	1.95
34	0.000812	45.8	1.055	0.795	1.33
33	0.000586	45.0	1.000	1.00	1.00
32	0.000564	44.7	0.980	1.32	0.742
31	0.000548	44.3	0.950	1.64	0.580
30	0.000532	44.0	0.930	2.03	0.459
29	0.000516	43.8	0.918	2.55	0.361
28	0.000502	43.3	0.858	3.11	0.276
27	0.000490	42.8	0.855	3.85	0.222
26	0.000480	42.0	0.810	4.60	0.176
25	0.000470	40.7	0.739	5.51	0.134
24	0.000460	38.6	0.635	—	—

comparison, and might have been easily mistaken for a green signal.

It is believed the results of the laboratory tests will be of interest from the photometric standpoint and that some pe-

TABLE XIII. SPECTRAL INTENSITIES OF REFLECTED LIGHT FROM A GREEN ROUNDEL WITHOUT LAMP

Setting	Wave length (cm.)	Average reading	Tangent squared	Tangent squared daylight	Ratio intensity to daylight
36	0.000668	34.3	0.465	0.425	1.09
35	0.000640	37.4	0.585	0.585	1.00
34	0.000812	41.1	0.760	0.795	0.955
33	0.000586	45.0	1.000	1.00	1.00
32	0.000564	49.6	1.38	1.32	1.05
31	0.000548	52.7	1.72	1.64	1.05
30	0.000532	56.2	2.22	2.03	1.09
29	0.000516	59.3	2.83	2.55	1.11
28	0.000502	61.0	3.25	3.11	1.04
27	0.000490	60.9	3.21	3.85	0.835
26	0.000480	59.4	2.85	4.60	0.62
25	0.000470	57.7	2.50	5.51	4.54
24	0.000460	—	—	—	—

TABLE XIV. SPECTRAL INTENSITIES OF REFLECTED LIGHT FROM A RED ROUNDEL WITHOUT LAMP

Setting	Wave length (cm.)	Average reading	Tangent squared	Tangent squared daylight	Ratio intensity to daylight
36	0.000668	36.9	0.562	0.425	1.32
35	0.000640	39.4	0.671	0.585	1.15
34	0.000812	42.0	0.810	0.795	1.02
33	0.000586	45.0	1.00	1.00	1.00
32	0.000564	47.8	1.21	1.32	0.916
31	0.000548	50.5	1.47	1.64	0.896
30	0.000532	53.0	1.75	2.03	0.862
29	0.000516	55.0	2.03	2.55	0.795
28	0.000502	56.8	2.33	3.11	0.750
27	0.000490	56.3	2.24	3.85	0.582
26	0.000480	55.8	2.16	4.60	0.470
25	0.000470	54.5	1.96	5.51	0.356

TABLE XV. SPECTRAL INTENSITIES OF REFLECTED LIGHT FROM A GREEN ROUNDEL WITH LAMP

Setting	Wave length (cm.)	Average reading	Tangent squared	Tangent squared daylight	Ratio intensity to daylight
36	0.000668	36.0	0.529	0.425	1.25
35	0.000640	38.3	0.622	0.585	1.06
34	0.000812	40.8	0.745	0.795	0.936
33	0.000586	45.5	1.03	1.00	1.03
32	0.000564	53.3	1.79	1.32	1.36
31	0.000548	57.0	2.36	1.64	1.44
30	0.000532	58.0	2.55	2.03	1.26
29	0.000516	57.5	2.46	2.55	0.965
28	0.000502	56.8	2.33	3.11	0.75
27	0.000490	55.8	2.16	3.85	0.561
26	0.000480	54.1	1.90	4.60	0.413

culiarities noted in the use of powerful headlights in railroad operation are explained thereby.

CONCLUSIONS

As a summary of the results, the following may be noted:

First. That the magnitude of the illumination is a function not only of the total light flux emitted from the lamp, but also its distribution.

TABLE XVI. SPECTRAL INTENSITIES OF REFLECTED LIGHT FROM A RED ROUNDEL WITH LAMP

Setting	Wave length (cm.)	Average reading	Tangent squared	Tangent squared daylight	Ratio intensity to daylight
36	0.000668	35.1	0.494	0.425	1.16
35	0.000640	38.9	0.650	0.585	1.11
34	0.000812	42.0	0.810	0.795	1.02
33	0.000586	45.0	1.000	1.00	1.00
32	0.000564	47.3	1.170	1.32	0.886
31	0.000548	49.5	1.370	1.64	0.835
30	0.000532	51.3	1.55	2.03	0.763
29	0.000516	52.5	1.69	2.55	0.663
28	0.000502	53.0	1.75	3.11	0.563
27	0.000490	52.9	1.74	3.85	0.451
26	0.000480	52.5	1.70	4.60	3.70

TABLE XVII. REFLECTION COEFFICIENTS OF ROUNDELS

Angle deg.	Green	Green with lens	Red	Red with lens
7½	0.0418	0.0478	0.05	0.0512
15	0.0375	0.0437	0.048	0.0514
22½	0.0352	0.0468	0.0486	0.0505
30	0.0413	0.0459	0.0467	0.0453

Second. That that reflector in which the largest proportion of total light flux falls in the vertex will have the highest multiplying factor.

Third. That the lens type of projector has a higher multiplying factor than the reflector type, other things being equal.

Fourth. That the spectral intensities of the luminous arc headlights are not noticeably different from those of the carbon arc, although the former are slightly lower in the red portion of the spectrum than the latter.

Fifth. That headlight No. 4 having a lower electrode of copper may so operate in practice as to produce relatively high intensities in the yellow-green portion of the spectrum. This is also true of headlight No. 3 with terminals reversed.

Sixth. That oil headlight No. 5 gives intensities higher in the red and lower in the green than all other headlights tested.

Seventh. That the reflected light from green roundels has a higher intensity in the green than that from red roundels and that this intensity is greatly augmented when a signal lamp is placed behind the roundel as in practice.

In closing this paper it is desired to acknowledge the very great assistance furnished the authors by their associates in the University.

NOTE

The following paper is to be read at the 27th annual convention of the American Institute of Electrical Engineers in **Jefferson, N.H., June 28—July 1, 1910.** This paper is to be presented under the auspices of the Telegraphy and Telephony Committee of the Institute. All those connected with the Institute and desiring to take part in the discussion of this paper may do so by being present at the meeting; or, if this is not possible, by sending in a written contribution.

Written contributions will be read at the meeting, time permitting, for which they are intended, either in full, in abstract, or as a part of a general statement giving a summary of the views of those taking the same position in the matter.

The principal object in getting out the paper in advance of the meeting is to enable and encourage those not in a position to attend the meetings to take part in the discussion by mail.

Contributions to the discussion of this paper should be mailed to **William Maver, Jr., Chairman Telegraphy and Telephony Committee, 136 Liberty St., New York,** so that they will be received not later than June 23, 1910. Written contributions arriving within 30 days thereafter will be treated as if presented at the meeting

(MAVER AND MCNICOL)

A paper to be presented at the 27th Annual Convention of the American Institute of Electrical Engineers, Jefferson, N. H., June 28–July 1, 1910.

AMERICAN TELEGRAPH ENGINEERING—NOTES ON HISTORY AND PRACTICE

BY WILLIAM MAVER, JR., AND DONALD MCNICOL

Although there may not be any startling technical announcements to make relative to recent progress in American telegraph engineering practice, yet within the twenty-five years past, in common with the progress in other lines of engineering, substantial developments have been also made in the telegraphic art along numerous lines, such as the standardization of equipment, and the adoption of improved apparatus and methods of operation which have generally resulted in increased efficiency of the plant, greater reliability of operation, a more rapid handling of the traffic, and consequent improvement in the service rendered the public; and which developments have, in fact, been adequate to meet the demands made upon the telegraph.

The time has been deemed opportune to record some of the salient features of present telegraph engineering practice in this country, but first in order more clearly to illustrate the differences between past and modern practice a resumé of the early history of telegraph practice in this country will be essayed in which resumé certain more or less interesting items of information relating to that history perhaps not hitherto published, or in any event not readily available, may be recounted.

The first electric telegraph line in this country was constructed by Morse in 1844 between Baltimore and Washington. The progress of this art into public favor was slow; due mainly to the necessarily high rates for service and to more or less imperfect service, the latter due largely to poorly constructed lines and the former to heavy legal expense incurred in the effort to maintain for the Morse interests a monopoly of the telegraphic art. Morse

endeavored to obtain a British patent for his electro-magnetic telegraph, but failed on the score of previous publication. Bain of Edinburgh came to the United States in 1848 to obtain a patent covering his chemical telegraph which was refused on the allegation that his device infringed the patents of Morse. Bain's telegraph consisted of a device for perforating long and short holes in a strip of paper, which were used to transmit long and short impulses of current over a wire. At the receiving end he used a sheet or strip of paper saturated with a chemical solution consisting of nitric acid 2 parts, prussiate of potash 20 parts and pure liquid ammonia 2 parts, which solution was decomposed by an electric current from the sending station thereby leaving long and short marks on the receiving paper sheet or strip. Bain pressed his claims in the United States Supreme Court and in the year 1849 a patent was finally allowed. A British patent to Morse would have been of doubtful value at that time, as during the life of the United States patent the Morse telegraph was but sparingly used in Great Britain, various needle and dial telegraph systems having obtained a strong foot-hold in that country.

The maximum speed claimed for the Bain system was about 1000 words per minute, but as a writer of that day remarked:[1] "The process of preparing the message to be transmitted, took quite as long as to transmit it" by the Morse method, and while "Mr. Bain's plan was entirely successful as far as it went it was found that after the quick receipt of a long dispatch, it would take about as long to copy it into manuscript as it would have taken to transmit it in the ordinary manner in the first place." Following the granting of the U. S. patent to Bain, numerous telegraph companies were organized and lines built on which the Bain automatic chemical system was employed, in opposition to the Morse Companies, but in 1850 an injunction was obtained, based on the charge that Bain's apparatus infringed the Morse telegraph patent of 1840. A consolidation of many of the chemical automatic companies with the existing Morse lines soon followed, and subsequently the Morse manual system (in which the Morse stylus recorder, or register was used) went into almost general use.[2] The Morse register was

1. "Electric Telegraph," (1852) Jones, pp. 110-150.

2. In a personal letter to Mr. Maver dated August 22, 1890, Mr. D. H. Craig who was a prominent figure in the early annals of American telegraphy, writes: "I used Bain's system on lines between New York,

gradually displaced by the reading sounder, but not without opposition on the part of the superintendents of telegraph who were apprehensive, needlessly as experience proved, of the introduction of errors thereby. The first printing telegraph was that due to Royal E. House[3] the use of which was begun in 1847–1848 and continued for many years in this country. This system employed a key-board the depression of a key of which resulted in the printing of a given letter on a strip of paper at the receiving station. The speed of transmission by this system was about 50 words per minute. It was operated on lines 1000 miles in length. The Morse interests endeavored to bring this telegraph printer within the scope of the Morse patents but were overruled by the courts.

In the early days of the electric telegraph the methods of line construction were naturally crude, but every year saw improvements in the direction of workmanship and materials used. Wooden poles were used from the first in this country, but the forms of insulators and the materials used in their construction were multitudinous, and it was not until much bitter experience was had with various "improvements" in insulators that practice converged on the glass petticoat form now universally employed in overhead electric telegraph work in this country. One of the so-called improvements termed the "brimstone" insulator was especially defective and nearly ruined several of the competing companies that employed it. This insulator consisted of an iron arm which screwed into an augur hole in the pole, the outer end of the arm carried a hollow pendant filled with sulphur into which an iron hook that upheld the line wire was inserted.

Boston and Portland between 1850 and 1853 and was able often in stormy weather to send to the Boston press columns of news when the Morse lines would not telegraph a word. We frequently, however, had trouble with "tailings" when the dots and dashes all ran together and made the record partially or wholly unreliable, so that in a message or series of messages of 500 or 1000 words there would be yards of record that would have to be discarded and the messages repeated. The later use of artificial resistances or magnets largely eliminated this trouble. Bain used on his early lines (for his chemical solution) nitrate of ammonia, 2 pounds to a gallon of water, and muriate of ammonia one pound to a gallon of water, and one-half ounce of yellow prussiate of potassia. This makes a fair solution, but we discarded it, (date not given) and substituted one half ounce red prussiate of ammonia and one pound of muriate of ammonia dissolved in one gallon of pure rain, or distilled water—iron pins were used with this."

3. Described in "Manual of the Telegraph," Shaffner, p. 391.

The civil war in this country, 1861–1865, again directed the attention of the world to the great utility of the electric telegraph in war and while its use at this time did not perhaps materially aid in the advancement of telegraph engineering it emphasized the value of the Morse telegraph system for this purpose because of its simplicity and reliability in operation.

The source of electromotive force for telegraph purposes in this country up to the year 1855 was the Grove cell, which was displaced by a modification of the Smee cell known as the Chester battery, and this battery in turn gave way to the Callaud or Gravity battery, of which up to the introduction of the dynamo machine in the year 1882, many thousands were in use. In some of the main telegraph offices 5,000 to 15,000 such cells were employed; entire floors of large office buildings being set aside for their occupation.

To meet the increasing demand for additional telegraph facilities in the decade 1870–1880, without resorting to the continual construction of additional line wires, the thoughts of inventors were directed to means for increasing the capacity of existing wires. To this end the chemical automatic telegraph, and the duplex and quadruplex systems of telegraphy were called into service. Thus in 1870 a compound wire of steel core and copper was erected between New York and Washington a distance of 275 miles on which a chemical automatic system due to Mr. George Little was employed. This system was a modification of the Bain chemical telegraph previously mentioned herein. Originally, adequate means were not provided in the Little system for diminishing the "tailings," or prolonged currents, due to the static capacity of the line, at the receiving instrument, in consequence of which the speed of signaling was low. Subsequently Little introduced a plain resistance in shunt around the receiver with beneficial results.

The Varley devices consisting of electro magnets in shunt with the receiver, and of condensers in series with the receiver[4] for the purpose of eliminating the tailings were subsequently employed, the electro-magnets probably first by H. Grace, to great advantage in this and certain other later automatic chemical systems in which a single row of holes in the perforated paper (and a uni-directional current) was employed; the condenser as thus employed virtually giving the equivalent of the double current method. Still later the speed of

4. British patent No. 3543. 1862. U. S. Patent 78495. 1868.

transmission on this New York–Washington line was increased to 900 words per minute by the substitution of an iodine solution and by using a platinum needle in place of a nitric acid solution and iron needle.

An important contribution to the art of chemical automatic telegraphy at this stage, was the Edison key-board perforator, which by the depression of a key perforated in a moving paper tape the characters necessary for any given letter. By the Little method of preparing the perforated tape not more than 7 or 8 words per minute was feasible, while with the Edison key-board perforator the tape could be prepared at a maximum rate of 40 words per minute, the average being about 25 words per minute. This key-board perforator while highly ingenious from a mechanical point of view was somewhat cumbersome in operation. The key board was about 18 inches in length, and the keys had a drop of about 2 inches requiring strong pressure to carry them down. As a writer of the period remarked " An hours work on one of these punches is a severe strain on the muscles of a strong man."[5] An important test of this system was made between Washington and New York, January 27, 1874 when the President's message on the Spanish " Protocol " consisting of 11,130 words was transmitted. This matter was prepared for transmission by ten perforators in 45½ minutes. The message was transmitted in 59 minutes. Time from the beginning of perforation until message received at distant end of the wire, 53 minutes. The time consumed in translating the characters by ten operators in New York was about 45 minutes, or roughly it required 72 minutes for the entire operation. Four Morse operators on 4 single wires, it may be remarked, are capable of transmitting a message of this length in 55 minutes. In the practical operation of this system by the Automatic Telegraph Company on its single wire from New York to Washington, D. C., during 1873–1874 business was frequently badly delayed by the breaking of the wire, there being no emergency wire, or alternate route. This fact undoubtedly mitigated against the commercial success of this system as must obviously follow in all cases where only a limited number of wires, or but one route between the important business centers are available. This automatic system[6] was subsequently employed, more or less in combination with the Morse manual system, on the lines

6. (Described in " The Electric Telegraph ", Prescott, Vol. 11, p. 727.)
5. " The Telegrapher," 1875, p. 109.

of the Atlantic and Pacific Telegraph Company until the year 1876, when it was gradually displaced by the Morse manual method of transmission.[7]

From about 1880 to 1884 the American Rapid Telegraph Company and its successors the Banker's and Merchants, and United Lines Telegraph Companies, operated a chemical automatic system known as the Foote & Randall system. These companies lines (compound copper coated wires) extended from Boston and New York to Washington, Pittsburgh, Buffalo, Cleveland and intermediate points. In this systemt he double-current method was employed. The prepared paper was perforated in two rows as indicated in Fig. 1.

Dots were represented by one hole on either side of the strip, the dashes by two holes. Consecutive dots, and dashes, were perforated diagonally on alternate sides of the paper strip as shown in the figure. Two metal drums *d*, *d'* connected with the positive and negative poles, respectively, of the battery were placed side by side in such a manner that one drum came under the holes on one side of the paper, the other under the holes on the other side. Transmitting needles or brushes *n*, *n'* connected jointly to the line wire were arranged so that each was in line with one row of holes on the paper. By the arrangement of the holes as shown each consecutive character of a letter, and the first character of a following letter were made by a different polarity to that making the preceding character and consequently all letters containing more than one character were represented by dots and dashes on alternate sides of the received paper strip.

7. About the years 1875-77, the widely advertised claims of the Atlantic and Pacific Telegraph Company relative to the advantages of the chemical automatic and wheatstone automatic telegraph systems controlled by that company were having a depressing effect on the stock of the Western Union Telegraph Company. Presumably to offset this effect President Orton of the last named company contracted with Messrs. Craig, Randall and Foote to pay $500,000 for a chemical automatic telegraph system that would be superior in every respect to that operated by the rival company. Tests were made of the new automatic system and the experts reported that all the technical conditions of the contract were fully met. Upon the sudden death of President Orton shortly thereafter however complications arose, a compromise offer of $250,000 being declined, whereupon the contract was abrogated and the inventors' interests in this system were turned over to the American Rapid Telegraph Company. It may be added on the authority of Mr. C. A. Randall that the inventors finally received about $15,000 as their portion of the amount received for the patents covering the automatic system bearing their name (W. M. Jr.)

At the receiving station needles *n*, *n'* were arranged in series in the line circuit as outlined, and rested on the sensitized receiving paper *p*. As the chemical solution is decomposed only by a current of positive direction, marks were made by the needle *n* with currents from battery *E*, and by needle *n'* with currents due to battery *E'*. In this system advantage was taken of the retardation of current due to the static capacity of the line in forming the dashes; the short perforations, all of uniform length, also limiting the time of contact of battery with the line, and thereby limiting the charge imparted to the line at each contact. The records thus produced were easily read by copyists. This system was capable of transmitting clear, legible characters between New York and Boston at the rate of 1000 words per minute, and 500 words per minute were ordinarily so transmitted. Messages were prepared by operators using the Anderson keyboard by means of which 30 to 50 words per minute could be

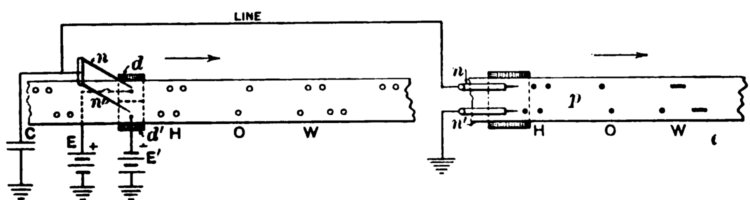


FIG. 1.—Foote and Randall chemical automatic telegraph

perforated, the machine operating with the ease of an ordinary typewriter. In June 1883, the American Rapid Company had in operation over 2,400 miles of pole line and 14,000 miles of wire. As already intimated this company began operations with the use of compound wires (6 ohms per mile) consisting of a steel core covered with a copper strip each weighing 200 lb. to the mile. This compound wire proved unsatisfactory, owing it was claimed to imperfections in manufacture which led to breaks or openings in the copper strips admitting moisture and ultimately causing the copper to peel off in long lengths. Subsequently No. 6 iron wire was employed as line wires by this company. The rates charged by this company in 1881 for transmitting messages was $1.00 for 195 words between New York and Boston, but experience showed this rate to be unprofitable and it was increased to 15 cents for 20 words. The Foote and Randall automatic system was set aside in 1884 upon the financial failure of the company.

In 1881 the "Leggo" chemical automatic system was installed by the Postal Telegraph Company between New York and Chicago (1,000 miles) on its two 1.7-ohm-per-mile wires (compound steel and copper) on which by the Leggo system 1000 words per minute were commonly transmitted. Taylor found by experiments on these wires that up to 400 miles, a speed of 400 words per minute was possible by the old Bain method; that is without compensating for line static,[8] but at a distance of 700 miles the signals arrived in a continuous black line. To remedy this defect Taylor introduced an extra battery E', Fig. 2 at the receiver R in opposition to the transmitting battery E. The e.m.f. of battery E' was one third of that of E. r, r' were adjustable resistances. With this arrangement a speed of 1200 words per minute was possible on this New York-Chicago circuit.

The method of preparing the messages for transmission by the

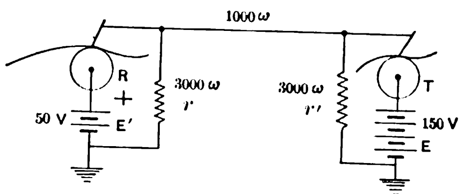


FIG. 2.—Taylor arrangement of Leggo's automatic telegraph

Leggo automatic system consisted in depositing an insulating ink spirally on a revolving metallic cylinder by means of a spout attached to the armature of an electro magnet operated by a relay or Morse key in a main or local circuit, somewhat analogous to the method by which speech is now indented on phonograph cylinders. The dots and dashes thus recorded were transmitted from the metallic cylinder at high rates of speed over the line circuit. An advantage claimed for this method of recording signals for re-transmission by Morse telegraphy was that the business originating at branch offices and way offices could be transmitted over through wires automatically without further preparation. The extra battery E' was kept constantly to the line during operation and at the instant when the transmitter needle or brush passed onto the insulated ink on the drum this negative polarity cut short the tailings.[9] The Leggo automatic

8. See *Electrical World*, May 24, 1884.

9. This arrangement of batteries for this purpose is perhaps suggested in Prescott's "Electric Telegraph," 1866, p. 137.

system was abandoned for lack of patronage after a comparatively short period of operation.[10]

Since the discontinuance of the American Rapid and the Leggo systems there has been no extensive employment of automatic chemical telegraphs in this country or elsewhere although workers in this field like Anderson and Delany have devised certain features designed to be conducive to greater reliability of operation and speed of translation of the received characters, notably perhaps the Anderson page method of recording the message which enables the attendant to observe the condition of the incoming signals as they arrive, and simplifies the reading of the characters by the copyist[11]. It also lends itself readily to means for drying the paper speedily as received, thus obviating, or minimizing an objection to "wet" strip, namely the tearing of the strip.

The well known Wheatstone system of automatic telegraphy was introduced on certain circuits of the Western Union Telegraph Company in 1883, and its use was continued thereon up to a comparatively recent period when it was[12] to a considerable extent displaced by the Buckingham-Barclay printer. Further reference will subsequently be made to this subject.

As previously stated the employment of duplex telegraphy began about the year 1868, and on short lines was practiced with a certain degree of success without any device to compensate for the static discharge from the main line. Stearns, however, applied the condenser to the artificial line for this purpose in 1872, whereupon the general use of the duplex ensued. Subsequently in 1873-74 the Edison quadruplex was placed in operation on the Western Union Telegraph Company's lines and after numerous modifications of apparatus and circuits finally reached its maximum efficiency about 1884. In the year 1886 there were about two hundred quadruplex sets in operation in the United States, these, it was estimated, providing additional, or "phantom" wire facilities equivalent to 150,000 miles of line wire, the value of which was approximately eleven million dollars.

Much of the success of the quadruplex system between the years 1885-1895 is no doubt properly ascribed to the extensive employment of hard drawn copper wire for telegraph purposes, beginning in 1885. The period indicated was also prior to the

10. See TRANSACTIONS A. I. E. E., 1897, p. 139.
11. See "American Telegraphy," p. 294.
12. *Ibid*, Chap. XXVII.

advent of high tension power transmission lines in proximity to telegraph circuits, the inductive disturbances from which undoubtedly have had a very detrimental effect upon quadruplex operation, and to which subject also further reference will be made.

As an instance of the extent to which duplex and quadruplex operation has been utilized in this country in proportion to existing wire mileage, it may be noted that in the case of the Baltimore & Ohio Telegraph Company which had a total of 50,978 miles of wire in operation in 1887, (reaching from Portland, Maine to Galveston, Texas, *via* New York, Washington, Chicago, St. Louis, etc.,) 23,482 miles thereof were assigned to the aforesaid duplex and quadruplex service, producing 56,553 miles of phantom circuits. Of the total miles of wire mentioned there were approximately 4,655 miles of No. 12 and 3,605 miles of No. 14 hard drawn copper;[13] 12,726 miles of No. 6 iron, 25,345 miles of No. 8 iron, 3,944 miles of No. 9 iron, and 252 miles of No. 12 iron wire.

In the years 1885-86 the Delany synchronous multiplex system[14] was in experimental operation on a circuit of the Baltimore & Ohio Telegraph Company's lines. On short lines this system gave the equivalent of six transmissions simultaneously, but owing largely to difficulties introduced by the static capacity of the line, its employment on long lines was not available at that time.

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13. This was doubtless the first extensive employment of hard drawn wire in telegraphy. At this time quite conflicting views were held as to the utility of this metal for overhead telegraph circuits. The advocates of silicon-bronze and phosphor-bronze wire claiming superiority for those materials. The experience of twenty-five years has, however, fully justified the favorable opinions of the pioneer users of hard drawn copper wire regarding its many advantages.

It may be further noted as an interesting item of telegraph history that owing to the expiration in 1880, through inadvertence of the Canadian patent No. 4608, of April 10, 1875, covering the Edison quadruplex, that system was unprotected by patents in this country after the first mentioned date. A legal contest was, however, waged by the Western Union Company against the Baltimore & Ohio Telegraph Company for infringement of Stern's patent No. 126,847, of 1872, covering the application of the condenser to duplex and quadruplex telegraphy. An injunction *pendente lite* was denied by the courts on the ground that the original Stearns patent had been so broadened by successive re-issues as to raise reasonable doubt as to its validity. The matter was still in litigation when the defendent company was merged with the Western Union Company in October, 1887.

14. Described in "American Telegraphy," Chap. XXI.

Sources of Electromotive Force in Telegraphy

As already noted herein gravity batteries as a source of e.m.f. for telegraph service have been almost entirely displaced in this country by machine generators. The type of generators used and the arrangement of equipment vary according to the local requirements.

In some instances the generators are driven by gas or steam power developed on the premises, but as a rule public service mains are utilized to operate the machines, either as motor-generators, or by means of separate electric motors. At points where the only commercial current available is alternating, it is customary to operate from this source an induction motor-driven direct-current generator which in turn furnishes power for the operation of direct-current motor-generators. In numerous cases where driving power to operate the motor generators is derived from public service mains, emergency gas or gasoline engines are installed to insure continuity of service in the event of prolonged interruption of the commercial power circuits. One method of arranging these machines in large terminal offices consists in arranging a certain number of them of equal voltage in series, thereby furnishing a range of e.m.f. from, say 40 to 400 volts, the machines being tapped by the various main line or local wires as required, the local and single wires taking from 40 to 150 volts, respectively, the duplex circuits taking current at 200 volts and the quadruplex circuits at about 350 volts. As currents of both polarities are employed in these systems, two sets or gangs of machines in series, as stated, are employed. Another method of arranging dynamos in terminal offices is to employ from 7 to 14 machines which deliver e.m.f.s ranging from 40 to 400 volts the lower voltage supplying current for the operation of sounder circuits, automatic repeaters, duplex and quadruplex pole changers, transmitters etc. an e.m.f. of 125 volts is used for main line simplex operation, generally way wires having a number of offices on the circuit. Machines supplying respectively 200 volts of positive and negative polarity are allotted to duplex operation, while 385 volt machines of positive and negative polarity, respectively, provide current for quadruplex circuit operation. The general arrangement and appearance of these machines are shown in the accompanying illustration.[15]

Storage batteries also have been utilized quite largely in telegraph service as sources of current for the operation of main line

15. Described in "American Telegraphy," pp. 47-227.

and local circuits. In general these batteries are charged from public service direct-current mains, or by locally operated direct-current motor-generators. The comparatively large loss in transformation of power, from the mains to, and in the storage battery itself, together with the cost of attendance and maintenance of the motor-generators and the battery have acted as a deterrent to its extensive use in telegraph work, notwithstanding certain advantages in the way of constancy and reliability of current that such batteries may possess. The engineering departments of the commercial telegraph companies and of the larger railroad

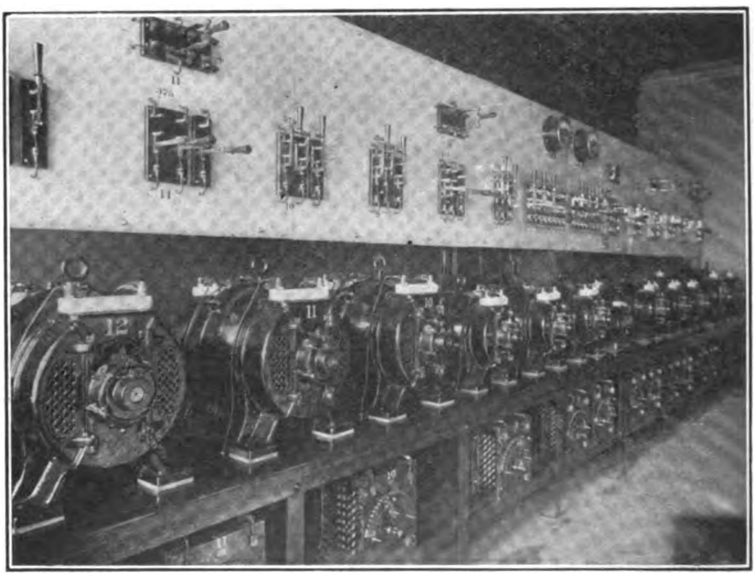


FIG. 2a.—Typical arrangement of motor dynamos in telegraph work

telegraph companies have therefore followed closely those developments in the electrical art which aim to procure equally efficient and more economical transformation of electric power for telegraphic purposes, and the claimed advantages of various alternating-current rectifiers—vapor, electro-mechanical, and electrolytic—have been considered and tested. At the present time, for example, quite an extensive application of the electrolytic rectifier is being made by the telegraph companies here, in order to determine what dependance may be placed upon these methods of obtaining practically constant direct-current potentials

from alternating-current sources. One of these rectifiers (the "Hickley") consists of a solution or electrolyte, say, phosphate of soda, and electrodes of carbon and aluminum, contained in a vessel *V*, Fig. 3, to which are attached radiator loops *R* which permit circulation of the solution (necessary on account of the heat developed in the electrolytic cell) thereby preventing the weakening of any portion of the electrolyte more than another. The direct current supplied by the rectifier is of course, pulsating, but owing to the condenser effect of the cells whereby a portion of the negative current is recovered, currents are derived which are sufficiently steady for average telegraph requirements. With this rectifier 80 volts direct current are procurable from 110 volts alternating current mains. The durability of the solution and electrodes of this rectifier depends largely upon the amount of energy delivered, but if not overworked the rectifier will not require renewal oftener than once each year; assuming daily operation of the device. A suitable transformer *T* is utilized to give either higher or lower voltage than that supplied by the available alternating-current mains, the rectifier being constructed to supply e.m.fs. ranging from 6 to 1000 volts. It may be noted also that some use is being made of small step down transformers of the bell-ringing type for the purpose of obtaining low voltages to operate call circuits, etc., operated in connection with telegraph systems.

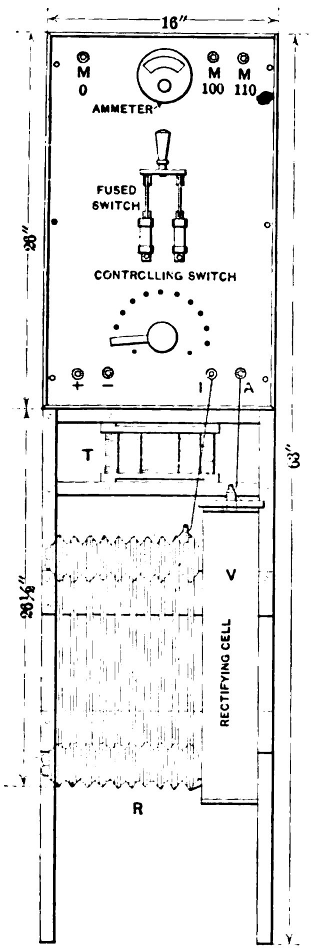


FIG. 3.—The Hickley rectifier

TELEGRAPH PRINTERS

It has long been recognized by telegraph authorities, that an ideal system of telegraphy would be a simple and reliable page

printer, capable of transmitting and receiving say from 600 to 1000 words per minute on circuits of from 200 to 1000 miles in length. To the inventor of such a system will ensue wealth and fame. It is hardly conceivable, however, that a telegraph printer can be devised that will not possess a number of prominent defects that will act against its general employment; for example, the necessity of preparation of the message for transmission, and its comparative expensiveness and complexity. The first defect would preclude its use on hundreds of stock exchanges and "broker" circuits; the second would debar it from thousands of small way wires. These disadvantages are inherent also in all automatic machine telegraph systems, electro-magnetic or electro-chemical. The superiority of the Morse manual system above all other systems in the foregoing respects is universally admitted.

Reference has already been made in the opening remarks of this paper to the "House" printer. This printer was followed in America by the so-called "Combination" printer, and by the Phelps printer,[16] and in Europe by the Hughes and the Baudot systems, all of which retain the objectionable features of printing the received characters on a strip of paper. Moreover these systems are comparatively slow in operation, not attaining a speed of more than 60 words per minute in one direction, or in each direction if duplexed, although the Baudot system when operated on the synchronous multiplex plan increases quite materially the carrying capacity of a circuit. For some time past in America efforts have been made to obtain higher speed page printing telegraph systems; that is, systems by which the received message will be printed on a regulation telegraph blank ready for delivery. Several different systems of this kind have been recently placed in operation in the United States, namely the Buckingham-Barclay[17] printer on the lines of the Western Union Telegraph Company, the Rowland multiplex printer,[18] experimentally on some of the lines of the Postal Telegraph Cable Company and the Wright printer, to be briefly described presently. The capacity of the Buckingham-Barclay printer is about 100 words per minute in each direction on a circuit 1,000 miles in length with repeaters midway. The capacity of the Rowland printer worked octoplex would be about

16. See "Electricity and Electric Telegraph," Prescott, Vol. II, p. 652.
17. Described in "American Telegraphy," Chap. XXVII.
18. Ibid.

280 words per minute on a circuit of moderate length, say 250 miles. The Buckingham-Barclay printer is quite extensively used at present and has been shown to possess marked advantages over its predecessors in printing telegraphy, and as previously noted has supplanted quite largely the Wheatstone automatic system in this country. It is possible, however, that a critical analysis now under way of the respective merits of these systems as regards rapidity, reliability, accuracy, and economy of operation may disclose results somewhat favorable to the Wheatstone system. It is not unlikely that, for the handling of the increased business due to public appreciation of the night "letter-gram" service recently inaugurated by the large telegraph companies in this country, resort may be had to the Wheatstone system or to one or other of the freely available rapid atuomatic telegraph systems mentioned herein, or to others that may be developed.* The merits of the Wheatstone system for service of this general nature has long been recognized in Europe especially in the Birtish Postal Telegraph department where it has attained a speed of from 400 to 600 words per minute on the shorter circuits.

One notable advantage over printing telegraph systems possessed by the Wheatstone or other automatic systems, in which the received messages are translated by a copyist (in common with the Morse manual method, but not by any means to the same degree), is that signals mutilated in transmission that would be beyond recognition in the printed record, may often be deciphered correctly from the tape by an expert copyist. Another important advantage of the Wheatstone system is that its main line apparatus is adaptable either to manual Morse or to high speed transmission by the simple movement of a small switch.

It must be noted, however, that the conditions now surrounding telegraph circuits (referred to elsewhere in this paper), such as high-tension inductive disturbances, and excessive retardation due to the presence of stretches of underground cable, were

*Under this "night letter" service the companies receive not later than midnight fifty word messages (or less) to be transmitted for delivery on the morning of the next ensuing business day at the standard day rate for ten words, one-fifth of the standard day rate for ten words being charged for each additional ten words or less in excess of fifty words in the night message. The companies reserve the option to mail these night telegrams at destination to the addressee. The messages must be written in plain English.

non-existent when the high speed automatic systems referred to were in practical operation, and these conditions, it may be anticipated, will reduce the speed efficiency in at least direct proportion to the sensitiveness of the respective systems. The night operation of such circuits, would, however, have the advantage of a minimum disturbance from parallel circuits, the exciting cause of which, except the stretches of underground cables, would be less in evidence. Unfortunately this does not apply to static inductive disturbances from adjacent high-potential transmission lines, which are in constant operation.

The Wright printer due to Mr. John E. Wright may be operated by ordinary typists unfamiliar with the Morse code as the transmitter is equipped with a standard typewriter keyboard which may be operated at typewriter speed, and the depression of a key of which selects a combination of positive and negative impulses, which, passing to line select a corresponding letter for printing at the distant receiving typewriter. The electro-mechanism of the transmitter prints a tell tale duplicate of the outgoing message in page form. The transmitting potential is 385 volts of each polarity. The line instrument is a polar relay of the duplex type that operates locally a magnet which in response to given combinations of incoming currents is designed to control the movements of a type-wheel, capable in operation of selecting and printing a given letter, of revolving around its axis, moving perpendicularly in the line of its axis, and laterally across the message blank at right angles to its axis, all of which movements are reversible. The receiving typewriter prints directly in message form the received telegram, the blanks being fed to the machine by an attendant who watches the copy during the printing to guard against errors. The disposition of the letters of the alphabet the numerals and punctuation marks on the periphery of the type-wheel is such that in practice it is found that regardless of the position of the wheel any letter may be selected and printed with an average of three and one half current impulses from the transmitter. The speed of this printer in operation on lines up to 300 miles in length is about 40 words per minute in each direction.

It may be noted that in America, telegraph operators during recent years have adopted extensively a keyboard, and other semi-automatic devices for the transmission of the Morse alphabet, which devices quite largely increase the rapidity and facility of transmission over the regulation key method. American

operators have also very generally adopted the typewriter for transcribing received messages. Primarily these instruments were adopted as labor saving devices, greatly reducing the mental and physical strain on the operator, and making it possible for operators who had " lost their grip " of key or pen, to return to the ranks of first class operators. The public appreciation of the typewritten copy was such also that the telegraph companies encouraged the use of the machine by increasing the compensation of typewriter telegraphers. Further, the use of the typewriter in combination with the marvelous abbreviations employed in the transmission of press matter, by code[19] considerably diminished the demand for rapid automatic or printing telegraphs, at least for that service, by bringing the performance of Morse working well up to what might be expected from printing

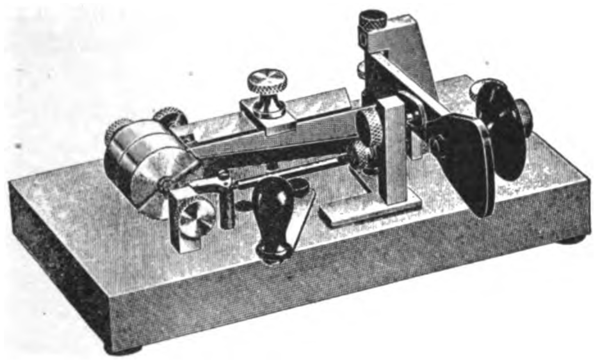


Fig. 3a.—The mecograph

telegraph systems. The semi-automatic transmitting key termed the Martin mecograph or modifications thereof is used by perhaps four-fifths of the operators of this country. It consists of a vibrating rod or pendulum which when moved to one side manually by the operator makes a dash, and when moved to the other side automatically vibrates (until stopped by the operator) in the act of so doing making any desired number of dots. It is estimated that 60 per cent more movements are required in sending by the ordinary Morse key than by this device, shown in the accompanying illustration, Fig. 3a.

Direct Point Repeaters

During recent years a demand has grown up for fast duplex telegraph service, in order to provide direct communication

19. See "Phillips Code," W. P. Phillips.

between large centres remotely separated. For instance, vast amount of traffic which arrives at, and which originates at the arge eastern cities of this country destined for China, Japan, the Philippines and other Asiatic countries requires that these cities shall have direct communication with the Pacific cable office in San Francisco. Formerly the arrangement of apparatus used in repeating from one multiplex set into another was that whereby the receiving relay controlled the sending transmitter through local connections, but the mechanical inertia of these instruments and the increased number of local contact points through which the operation was controlled did not conduce to high efficiency. The duplex repeater now used on both the Western Union and on the Postal Telegraph lines is known as the "direct point" repeater, and is similar in operation to the Wheatstone duplex repeater. By referring to Fig. 4 it will be seen that the arriving signal from the east will actuate the right

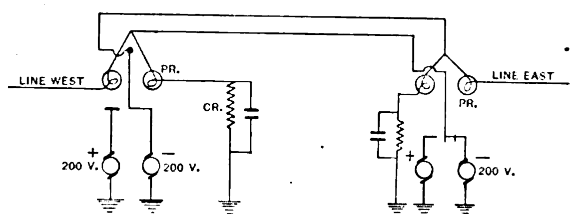


FIG. 4.—Direct point repeater

hand polar relay $P R$, thus placing for instance the armature of that instrument in contact with the 200-volt negative, e.m.f. which is given an outlet through the left hand polar relay to the line west, and in like manner signals arriving from the west are relayed to the line east by a reverse operation. It is now customary to wire up polar duplex and the polar side of quadruplex sets so that this efficient method of repeating may be utilized. Inasmuch as the local contact points of the polar relays are in this case employed to deliver line currents, special devices are provided to control local circuits for operating the reading sounders. For instance, in the Western Union type of duplex repeater the polar relays are equipped with double armatures, mechanically jointed together, but separated electrically, one contact controlling the line potentials, and the other the local circuit. The method employed by the Postal Telegraph Company is the well known "leak" arrangement. A single

tap is taken off the armature contact of each polar relay and led to ground through a polar relay and a 20,000-ohm coil. Another method of accomplishing the same result is to substitute a 0.5-m.f. condenser for the 20,000-ohm coil thus obtaining the same response in the polar relay without any loss of current through the leak coil to ground. Indeed when the condenser is used in place of the leak resistance, the polar relay may be done away with, the circuit leading directly from condenser through a sounder and to ground. In this latter case the armature and stop adjustments of the sounder are set so that the signals are all made on the upper stop screw.

The type of duplex telegraphy now universally employed in this country is that in which the well known double-current principle is employed, and by means of the direct repeating relays

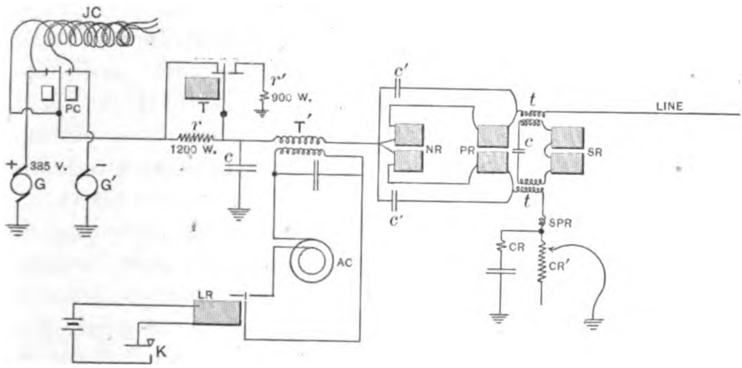


FIG. 5.—Phantoplex on quadruplex circuit

mentioned, very long distances are spanned, for instance across the continent from New York to San Francisco, by many diverse routes. Ordinarily from four to six repeaters are used in these transcontinental circuits, and the speed of transmission is at least equal to the ability of the operator to manipulate the key. Ordinarily the differentially-wound polarized relay is employed.

SUPERIMPOSED SYSTEMS. "PHANTOPLEX" AND VAN RYSSELBERGHE

Since Varley[20] there have been many workers whose aim it has been to increase the capacity of a single wire or a wire already in operation as a duplex or a quadruplex by superimposing thereon one or more pulsatory phantom circuits.

In the accompanying diagram (Fig. 5) is shown an arrange-

20. Varley's British patent, No. 1044, 1870.

ment of a "phantoplex" circuit on a quadruplex circuit that is in actual operation in many places in this country and by means of which a "sextuplex" is obtained.

In the figure one station only is shown. *G*, *G'* are the sources of e.m.f., for the quadruplex. *P C* represents the pole changer, *T* the transmitter with its shunt and leak resistances; *N R* indicates the neutral relay, *P R* the polar relay, and *C R*, *C R'* the compensating resistance of the quadruplex system the local circuits of which are omitted in the drawing for the sake of clearness. As the operation of the quadruplex is generally understood,[21] it will be necessary only to describe the phantoplex portion of the system. *A C* is a high frequency generator, the circuit of which is controlled by a local relay *L R* and a key *K*. In the circuit of *A C* is a transformer *T'* the secondary coil of which is in the transmitting portion of the quadruplex system. Condensers *C* and *C'* provide a path for the high frequency currents past the quadruplex relays. *t* and *t'* are small transformers, the primary of *t* being in the main line, the primary of *t'* in the artificial line; and in the secondary circuit of which transformers is the phantoplex polar relay, which in turn operates a reading sounder not shown. This arrangement of transformers *t*, *t'* obviously renders relay *S R* irresponsive to the outgoing currents of *A C*, but still permits it to respond to the high-frequency currents from the distant station. An unretarded path for the pulsatory currents is provided by a grounded condenser *C* at each station. The high-frequency currents of the phantoplex circuit are of a strength below that necessary to operate the quadruplex relays, but the armature of the phantoplex relay *S R* being properly biased by spring tension responds to the high frequency currents. Incidentally there is shown in this figure at pole changer *P C* a "coil" condenser *J C* known as the "Johnson" coil consisting of three separate coils of German silver wire wound on a wooden bobbin with an air core, the spool being about seven inches long and an inch in diameter. The coils are thoroughly insulated from one another by a double covering of cotton saturated with paraffine. One end of each winding is left open, the other end being connected as shown in the diagram. This device is efficacious in eliminating the sparks at the contact points of the pole changer.

In many cases Morse duplex circuits or portions of them are used simultaneously as telephone circuits, the wires of two such

21. See "American Telegraphy," p. 217.

duplex telegraph circuits being employed as one metallic circuit for telephonic purposes. One such arrangement is depicted in Fig. 7. Here *P C*, *P C* may represent the pole changers at a terminal (or a repeating station as shown in Fig. 4) of two duplex circuits, furnished with e.m.f. by generators *G*. The Wheatstone bridge method of rendering the polar relays irresponsive to the home pole changers is used, the arms of the bridge being formed of a double retardation coil *R C* which is found to be an efficient, practical device. In some cases the armatures of the polar relays *P R* are equipped with retractile springs so that the polar duplex apparatus may be availed of for simplex operation when desired, which result is accomplished by disconnecting one contact *b b* of the pole changer from a generator. These relays also have double local contact points on the armature levers *a*, *a'* shown theoretically in the figure, one of which controls the local reading sounder *S*, the other sounder *S'* in a branch office. The telephone apparatus utilizing the two duplex circuits *D C*, *D C* is shown at *T*. *c*, *c*, *c*, *c*, represent 4 m.f. condensers; *i*, *i* are 30-ohm retardation coils. This arrangement of the telephone, in one instance, is used successfully on duplex telegraph circuits to a distance of 360 miles, the entire length of the duplex circuits being 1000 miles without repeaters.

Composite circuits (originally the Van Rysselburghe simultaneous telegraph and telephone system)[22] are employed in this country and Canada very extensively; notably by the American Telephone & Telegraph Company, also by the telegraph departments of large railway systems. Between New York and Boston alone at least fifty leased telegraph wires are in daily operation on long distance telephone circuits, and this dual use of circuits is being rapidly extended in telegraph practice, all new line construction being designed with this end in view as noted elsewhere herein, the increased earning capacity of the wires gained thereby being the obvious incentive thereto.

Inductive Disturbances on Telegraph Circuits

In the pioneer days of telegraphy when routes were being sought for pole lines, the rights-of-way of the existing steam rail-

22. For an account of the first experiments with this system (which has now grown to such large proportions) by Prof. F. Van Rysselberghe in this country (1885-1886), see article in *Electrical World*, October 6, 1888, by William Maver Jr., by whom also it may be of interest to note the first set of Van Ryssellberghe's apparatus for simultaneous telegraphy and telephony was by request installed experimentally on a circuit of the American Telegraph and Telephone Company between New York and Philadelphia in the Spring of 1890. (March 1-5.)

roads were utilized wherever possible for the obvious reason that, as the proper movement of trains required the constant use of the telegraph, the questions of construction, maintenance, and prompt repairs were thus solved to the best advantage of the railroad and the telegraph companies. The growth of telegraph traffic was however, rapid, and between the larger centres, at least, duplicate pole lines on highways were soon required to carry the constantly increasing number of wires, and thereby one of the advantages of railroad routes for commercial telegraph lines was largely diminished. In the course of events also the time arrived when the displacement of the steam locomotive by the trolley car and electric locomotive for train haulage, introduced the high-tension transmission circuit, which, being naturally

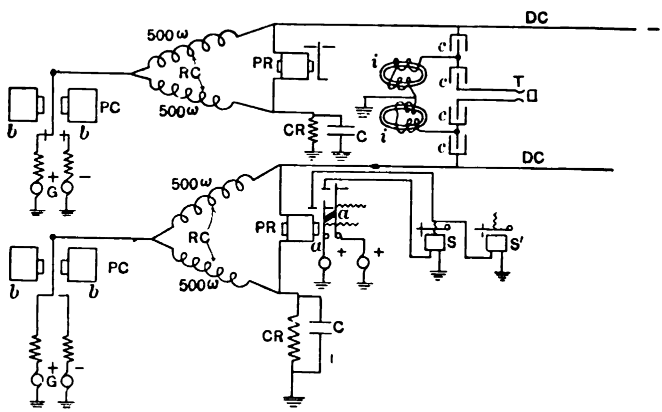


FIG. 6.—Simultaneous (duplex) telegraph and telephone

erected along the railroad tracks, at once menaced the value of a railroad right-of-way for telegraph purposes. It developed, also, that long distance transmission lines carrying high-tension alternating currents in numerous instances began to parallel the railroad rights-of-way as generally affording the most direct and favorable routes between cities, thereby adding another disturbing factor to telegraph lines following the same routes.

Apart, however, from the serious inductive disturbances due to the close proximity of high-tension lines, the subject of inductive disturbances on telegraph lines is not a new one, for mutual inductive disturbances between telegraph circuits were encountered as remotely as 1876 in the dry climate of some of the western states, on lines operated as simplex Morse circuits ex-

tending from Omaha, Nebraska to Salt Lake City, Utah. Upon the introduction of the quadruplex shortly thereafter mutual induction between parallel wires manifested itself as a disturbing factor at numerous points, due to the comparatively high e.m.f.s then used on quadruplex circuits, about 300 volts; and as in the ordinary operation of telegraphy single wires grounded at each end are employed, the well known method of transposing the wires at intervals to obviate mutual induction effects was not available as a remedy. Fortunately the reduction of efficiency due to this source of inductive disturbance was not very marked, and could, generally speaking, be overcome by an increase of e.m.f. at the terminal stations to 375 or 400 volts.

One of the first methods suggested to eliminate, or ameliorate the disturbances due to mutual induction was devised and tested by Mr. Chas. H. Wilson in 1876, in the western part of this

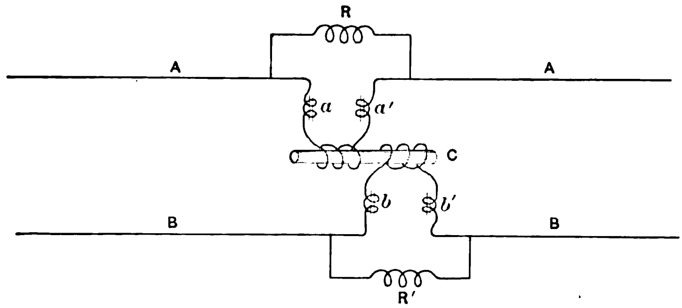


FIG. 7.—Wilson mutual induction neutralizing device

country. The method is indicated in Fig. 7 as applied to single wires. The object of the arrangement is to set up by means of small transformers *C*, currents in wire *A*, opposite to those induced in wire *A*, by wire *B*, and contrariwise. *R*, *R′* are adjustable resistances, *a*, *a′*, *b*, *b′* are small choke coils. This arrangement was subsequently used on quadruplex lines between Chicago, Buffalo, and Pittsburg, but not very successfully owing to the lag caused by the employment of the transformers *C* in the circuit which augmented the period of reversal to such an extent that the No. 2 side of the quadruplex systems was detrimentally affected thereby.

The continual extension of power transmission and other high potential circuits in close proximity to telegraph circuits however created inductive disturbances so inimical to the operation of the telegraph that further means were sought to effect a remedy,

short of changing the route of the telegraph pole lines, and a number of corrective devices have been suggested some of which in practice have been fairly successful under certain conditions and in certain localities, but have not always met the requirements elsewhere.

One of these means of obviating harmful induction from high tension power circuits on single Morse wires, due to Mr. E. W. Applegate is shown in Fig. 8 in which a resistance *R*, consisting of a carbon stick is connected across the main line contacts of the relay *M L*. By means of this shunt the rapid induced currents from neighboring alternating current circuits are given a path past the relay, and chattering of the armature is further avoided by increasing the tension of the retractile spring *S*. It was found that these devices tended to impede the action of

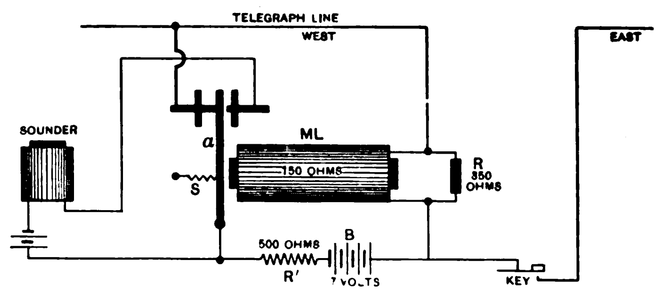


FIG. 8.—Applegate " Static pick-up."

the armature *a*, to overcome which tendency an extra battery *B*, of six cells are added, which by partly magnetizing the relay cores when the armature is on its back stop, effects this result. This device which is termed a " static pick-up " has been successfully used on a number of telegraph circuits where metallic circuits had been resorted to owing to the inductive disturbances from a frequently unbalanced 60,000-volt three phase system that parallels the telegraph circuits for a distance of eleven miles. The employment of this arrangement made it possible to resume single wire operation.

Another plan for obviating inductive disturbances on telegraph wires, due to Messrs. Blakeney and Chetwood, is shown diagrammatically in Fig. 9. *A C* is the disturbing line. When key *K* is open the induced currents oscillate harmlessly to earth via *i' c'*, and *n'*, while the regular Morse signals traverse the relay

coils *via* the inductive resistance n, and non-inductive resistance n', when key K is closed.

A brief description will now be given of one of the more recent methods put into practice for the purpose of offsetting inductive disturbances on telegraph circuits due to the close proximity of high tension electric traction circuits resulting from the electrification of the New York, New Haven and Hartford Rail-

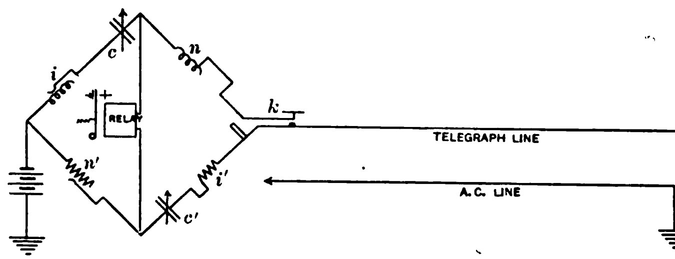


FIG. 9.—Blakeney and Chetwood inductive disturbance diverting device

way. To nullify electro-magnetic induction, current transformers $C\ T$ with a 1:1 winding, Fig. 10, are inserted in the telegraph lines at intervals of two miles. To neutralize electrostatic induction the secondaries of potential transformers $P\ T$ are used in connection with condensers C as outlined in the figure. The primaries of the transformer are placed in a special neutralizing wire or in the disturbing wire itself. By placing a

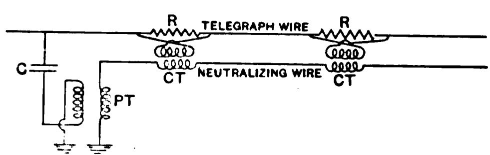


FIG. 10.—Taylor inductive disturbance neutralizing device

number of secondary coils in multiple, one neutralizing wire may suffice for a number of telegraph wires. As the neutralizing wire is subject to the same inductive effects as the telegraph wires, the currents developed in the former may be arranged to oppose those due to the disturbing wire.[23]

23. For further details of this general subject see "Telegraph and Telephone Systems as Affected by Alternating Current Lines", J. B. Taylor, Trans. A. I. E. E., Oct. 1909.

It has been found in practice that the neutralizing of inductive effects by the foregoing arrangement is seriously interferred with by escapes from direct current trolley lines which enter and energize the transformers. Variations in load on the alternating current line, phase distortion, etc., also add materially in preventing anything more satisfactory than an amelioration of the harmful inductive effects. Furthermore, in this particular case, the slight improvement noted is obtained at the loss of three copper neutralizing wires, in addition to the first cost and maintenance of the additional apparatus required. In general it may be stated that the various devices offered hitherto as inductive disturbance correctors have been rather of a palliative than of a positive remedial nature, and inasmuch as the tendency is to increase the use and the potentials of high tension transmission circuits, it appears evident that to meet or evade this situation successfully constitutes the most serious problem now confronting telegraph engineers. The basis of a solution of the problem may possibly be found in subsequent remarks herein.

Main Line Relays

The ohmic resistance of relays used in Morse telegraphy has undergone numerous variations during the past forty years in this country. Relays wound to 1200 and 1500 ohms were not uncommon. At one time the resistance of main line relays was calculated on the assumption that for the best results the total resistance of the relays in a circuit should be equal to the resistance of the line wire.[24] Thus on a circuit 300 miles in length, measuring, say 15 ohms per mile, with fifteen stations on the line, the relays would be wound to 450 ohms. There was, however, little or no uniformity in the winding of the relays and but little supervision of the quality of the copper used in the winding, which in the early sixties of the last century varied in commercial copper from 14 to 85 per cent that of pure copper. Measuring instruments of accuracy were at the time referred to a rarity in this country and no proper methods of ascertaining the condition of the lines as regards electrical resistance and insulation were in vogue. In 1867 the late Mr. C. F. Varley, the well known English electrician, was retained by the Western Union Telegraph Company to visit the United States for the purpose of making a thorough investigation of the electrical conditions of the lines and apparatus of that company.

24. "Modern Practice of the Telegraph", Pope, 1869 p. 125.

Following a thorough study of the subject supplemented by hundreds of tests of the lines, insulators, relays, batteries, etc., Mr. Varley presented a voluminous report to Mr. William Orton, President of the Company, December 20, 1867.[25]

The report detailed in extenso, the condition of the equipment as disclosed by the tests, and made numerous recommendations for the improvement of the general service, among others, the making of soldered joints, a reduction in the resistance of the relays used, and their re-winding to a uniform resistance of 130 ohms, the wire used to be the best copper obtainable. He also recommended that fewer poles per mile be used in line construction and that a smaller number of wires be worked from one main battery—in fact that a separate battery be provided, for each wire.

Prompt action was taken upon Mr. Varley's report and recommendations, and very marked improvements followed thereafter. Mr. Madison Buell, for instance, in an article on "Low Resistance Relays",[26] recounts that on the important circuit on which the Atlantic cable traffic between New York and Plaister Cove, N. S., was transmitted the repeaters were found to have relays ranging in resistance from 500 to 1,500 ohms. The relay of the "Milliken" repeater at St. John, N. B., has a resistance of 1,500 ohm. The relays at Boston, Portland, and Bangor had an average resistance of 1,200 ohms. All of these relays were rewound to 80 ohms. Also, many improvements were made in wire jointing, insulators, and leading-in wires at all offices, with the result that whereas on this circuit before these changes were introduced six repeaters were necessary in bad weather and in clear weather three to four repeaters, after the aforesaid improvements were made but two repeaters were required in bad weather, and only one in clear weather to operate the circuit at top speed.

In the course of time, however, relays of 150 ohms were adopted for simplex Morse circuits. For duplex and quadruplex service the neutral relays were wound to 200 ohms, the polar relays to 400 ohms, (each coil of the differential windings) and for many years these resistances have been the standard. Within the past 8 or 10 years, however, there has been a still further reduction of the

25. Report of Cromwell F. Varley, Esq., "On the Condition of the Lines of the Western Union Telegraph Company." Mss. by Mr. J. D. Reid, lithographed. Copies in Wheeler Library, also in Mr. Maver's library and probably in that of the Western Union Telegraph Co.

26. *Telegraph Age*, Jan. 1, 1903.

resistance of main line relays (to 37½ ohms) on many of the commercial and railway telegraph way wires with a very pronounced improvement in the operation of the circuits, especially in bad weather. At the present time the tendency of American practice is to the employment of lower e.m.f.s at the terminals of the circuit and to lower resistances in the relays for multiplex working. During the period when No. 9 iron wire was the standard for telegraph purposes, and when the insulation resistance of the lines, was far below present day standards, a high e.m.f. was necessary in order to maintain proper current values, but by the substitution of low resistance copper conductors in place of iron wire and with improved line construction, the way has been paved for the employment of lower voltages, and relays of much reduced resistance in multiplex operation. Thus some very satisfactory results have been obtained recently in different parts of the country on quadruplex circuits using e.m.fs. as low as 200 volts on well insulated lines of comparatively low resistance (2 ohms per mile) and with polar relays wound to 100 ohms and neutral relays to 50 ohms. The length of the cores of these relays has been somewhat increased. The "potential" resistance of 600 ohms (usually inserted between the current generators and the multiplex apparatus) in these instances has also been reduced to 300 ohms, and the "proportion" resistance and "leak" shunt in the field key system from 1200 to 600 ohms, and from 900 to 450 ohms, respectively. The objective in these modifications of the prevailing practice is to reduce the inductive effects upon parallel circuits and to render the relay less sensitive to inductive disturbances from any source.

Some Telegraph Engineering Details

It might be supposed that telegraph engineering has to do mainly with purely physical and technical questions, but the close relationship existing between the handling of traffic (telegrams, leased wires, etc.) and the machinery employed in handling it, is such that the telegraph engineer, perforce, finds himself involved in the study of traffic details which he cannot well omit without loss to the economies of operation. This for example obviously requires keeping in the engineer's department an accurate record of existing wire facilities, data as to the daily efficiency of operation of all circuits (especially multiplex and automatic circuits) and information as to their electrical condition, together with carefully prepared tabulated records of

details pertaining to methods of traffic movement and the amount of traffic handled on the respective circuits throughout the system, in order at once to enable the engineers to determine whether existing facilities are being utilized to the best advantage, or whether additional facilities, or modifications of the arrangement of present facilities may be deemed advisable. Information of this kind is especially important as a guide in the matter of underground construction and cable work extension. Thorough engineering organization and the application of engineering principles to all work under way or prospective also results, among other things, in placing the engineer's department in a position to intelligently and promptly decide all strictly engineering and related traffic questions that are continually arising in the operation of a large telegraph system.

The graphic method of mapping circuits indicated in the accom-

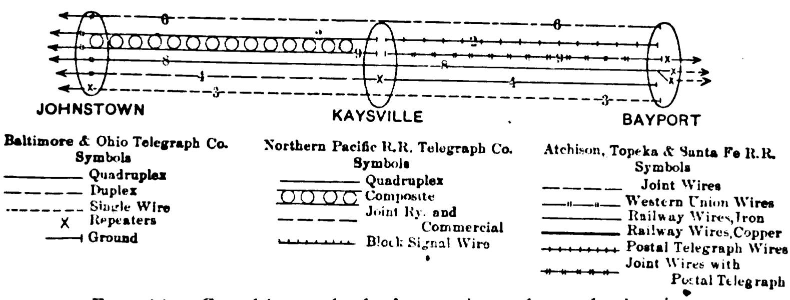


FIG. 11.—Graphic method of mapping telegraph circuits

panying diagram Fig. 11 to show at a glance the routes of the various wires, their allotted numbers, how operated, offices entered, material of wire, by whom owned, etc., has been found of great utility wherever used. The scheme which is clearly susceptible of many amplifications was probably first employed in the engineering department of the Baltimore and Ohio Telegraph Company in 1885–88 by one of the present writers and it may be of interest to note that details of the nature indicated relating to over 50,000 miles of actual wire were shown on a map four feet long by 3 feet wide. The accompanying specimens of blank forms for certain reports were also used in the operation of the same company, the information derived therefrom enabling the engineer's department to maintain an intelligent supervision of the circuits, that resulted in a clearly perceptible enhanced earning capacity in the case of numerous circuits. Somewhat contrary to

TRAFFIC BLANK

To...Supt CLEVELAND, O., FEBRUARY 15, 1886

Statement of Messages Handled in this Office For the Week Ending..................................

No. of Circuit	From	To	Single	Duplex	Quadraplex		DATES. Messages Sent and Received.						
					A Side	B Side	1	2	3	4	5	6	7

To...Supt. INDIANAPOLIS, IND., FEBRUARY 13, 1886

Report of the Working of the Single and Multiplex Systems in this Office, Week Ending Sat., Feb. 20

Date	Name of Circuit	How Assigned	Commencement of Delay	Termination of Delay	Nature of Delay

expectations these reports were prepared by chief operators or clerks at no additional expense. As will be readily understood the knowledge that the operation of all circuits was under constant impartial supervision was not overlooked by those directly in charge of the operation of the circuits.

A knowledge of the condition of the insulation resistance and conductivity of every circuit, open or in cables is manifestly of great importance to the engineering department and reports of the tests of conductors for these properties are promptly forwarded to the engineer's department periodically.

The Telephone in Electrical Testing

In America the tangent galvanometer has long since been set aside and simpler and quicker methods of circuit testing and fault localizing have been adopted. Many tests, such as those for insulation resistance and conductivity are now made with high resistance voltmeters, especially where earth currents from adjacent grounded trolley circuits (which frequently indicate an e.m.f. of 15 to 20 volts) are not troublesome. The milliammeter is also used for making insulation resistance measurements not exceeding one megohm and for other electrical tests. The telephone receiver is used as an indicator in many tests. This instrument in connection with an "exploring" coil is largely utilized for localizing faults in aerial cables and in underground cables, especially where the latter are laid in conduits. In making these tests a high frequency current is established in the defective conductor and the exploring coil, a semi-circular coil of fine wire in circuit with the telephone, is moved from point to point along the cable sheath, the indications in the telephone increasing or diminishing as the defect is reached. The telephone receiver as a testing device is particularly advantageous for practical purposes as it places in the hands of the electrical worker or "trouble hunter", an instrument at once portable, and easily understood, and one that is not readily deranged by rough handling. Where a head-band is used to support the receiver, the hands of the workman are free.

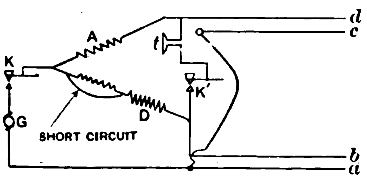


Fig. 12

For quickly determining by means of the telephone as an indicator the distance of a break in a cable conductor when the

insulation is normal, one method is as follows: Select three conductors similar electrically to the open conductor b and adjacent to each other, a, being next to b; c, being next to d and connect as shown in Fig. 12. G, is a source of alternating current. For cables approximating 1000 feet in length the generator should give from 40 to 130 volts. The resistance of arm A may require to be 100, or 1,000 ohms. To make this test the four wires should be opened at the distant end. Keys K, K' are then closed and the resistance of arm D or rheostat is varied until minimum sound is heard in the telephone receiver, when:

$$\frac{L\,R}{R'} = F$$

where L is the length of the cable in feet, R, the resistance of arm A, R' the resistance of rheostat D, and F is distance to break in feet.

The Varley and Murray tests are still the standards for making accurate measurements or faults in conductors, and the Wheatstone bridge method for accurate resistance measurements.

Pole Line Construction—Aerial versus Underground Conductors—Notes on Duplex and Quadruplex Operation

Owing to the confusion and general disarrangement of business that usually follows the prostration of the telegraph wires by severe sleet or wind storms in this and other countries, every notable occasion of this kind has been followed by insistent demands on the part of the interested business communities that measures be taken to prevent a recurrence of these disarrangments. So much has this been the case that in Great Britain, at least, where such storms are quite frequent, and where owing to the geographical shape of the country the loss of telegraphic communication due to the effects of such storms has been felt with peculiar force, these demands have been met by the British government in the laying of an emergency telegraph cable between London and North Britain. The fact that such unanimous demands are made for the prevention of even a temporary loss of the telegraph between important centers is, it may be remarked, a rather notable acknowledgement of the indispensibility of this public utility as a part of the commercial and social structure of a country.

Apart from the very important matter of maintaining uninterrupted telegraphic communication regardless of weather conditions in the interests of the general public it may safely be assumed that the various telegraph authorities in this country have not been unmindful of the financial losses sustained by the telegraph upon the occasion of each recurring collapse of poles and wires, and that every possible remedy therefor has been most carefully considered. Furthermore, telegraph lines are not only subject to widespread damage from abnormally severe sleet and snow storms, but are also in many places exposed to the ravages of forest fires, avalanches of snow, washouts due to floods, and to destruction by lightning. Again the average life of a pole line in all parts of the country probably does not much exceed ten years. Consequently, if the financial and engineering difficulties in the way of placing telegraph wires underground on a large scale had not been practically insurmountable, that solution of the problem, unquestionably, would have long ago been adopted. But it is well known, for instance, that the increased static capacity and mutual induction of the conductors carried in cables reduces very materially the length of circuit that may be used in satisfactory telegraph operation. Already indeed the presence of a comparatively limited amount of underground cable in the circuits passing through the principal cities of the country has very preceptibly reduced the speed of signaling, and the general efficiency of automatic and multiplex telegraph circuits in this country. Being therefore aware of the great technical and financial difficulties that would attend the placing of wires underground generally between cities and towns over the expansive territory of this country, the question of building stronger pole lines, and of employing larger and stronger wires has been frequently proposed by telegraph engineers. The well known " A " and " H " methods of setting wooden poles have of course received due consideration, and in trials have been found to add considerably to the stability of lines. In addition however to doubling the expense for poles, further objection to the use of these methods, especially where the telegraph lines are on a railroad right of way, is the extra space required for setting, which very often is not obtainable. Another plan tested was that of using worn out track rails, set up in " H " form and braced one foot apart. The cost of setting these rails is, however, rather high, being about eleven

dollars per unit. In especially exposed places the plan of doubling the number of poles from say 50 to 100 per mile, has been adopted with considerable success. A reduction of the height of poles and an increase of their girth has also been advocated and there is now a tendency in that direction. It is very probable that pole lines built in the future will when possible be built of poles considerably less than 35 feet in height (the present general practice) with head and side guys located about every half mile regardless of the contour of the line. On heavy loaded lines with the poles set about 100 feet apart reduction of the leverage obviously increases the efficiency of guying. In the construction of a thirty-wire line by using ten-pin cross arms a 25-foot pole would generally leave sufficient clearance.

The employment of re-inforced concrete poles for telegraph purposes has been suggested as offering a solution of the problem as regards durability and reliability[27] but has not gained much headway hitherto, principally owing to the present high cost of such poles and also to the excessive cost of transportation. Even, however, if experience should show that cement poles will possess the ability to withstand the strains brought to bear on them by wires heavily coated with sleet, there still remains the unfortunate fact that the wires themselves may break under the strain. It would of course, be a decided gain to avoid the total loss of miles of pole line by the collapse of the poles like bricks in a row—a not infrequent occurrence under present conditions.

In relation to the immediately foregoing remarks, it may not be amiss to digress here to suggest that since the telegraph lines are not put up merely for a day or a year, that a combination of concrete poles, or towers of equal strength and durability with perhaps some form of housing for the wires along permanent and isolated rights of way may be among the possibilities of future telegraph engineering, since such a plan offers promise of reliability of operation without the detrimental accompaniment of impaired efficiency of the telegraph service that follows the placing of telegraph conductors underground. In view of the importance of the subject further reference may here be made to the reduced efficiency of quadruplex telegraph operation within recent years, in some cases amount-

27. (See paper by Mr. G. A. Cellar, "Experiments with Concrete Poles" Proceedings, Association of Railway Telegraph Superintendents, 1907, p. 144)

ing to 50 per cent, due to the increased amount of telegraph conductors placed underground in cables in cities. In other cases certain quadruplex circuits have been abandoned because of inductive disturbances from parallel high tension transmission lines. It is a well established fact that prior to the introduction of these disturbing factors, duplex and quadruplex telegraphy in this country had attained a high degree of efficiency. Thus, for instance, it was formerly common practice to operate four, six or more quadruplex circuits between New York and Boston on open parallel lines, each with an efficiency equivalent to four wires worked simplex, and certain quadruplex circuits between New York and Chicago were operated as a rule with an efficiency of at least 9 per cent.

In the equipment of the quadruplex circuits to which special reference is now made, the ordinary horse-shoe polarized relay, with flat armature, and short cored neutral relay were employed without any devices to aid the operation of the No. 2 side excepting the Edison device of the back contact and repeating sounder attachment to the neutral relay. It is well known also that in isolated sections at the present time quadruplex circuits are still operative at high efficiency. It would appear evident therefore that a restoration of the original efficiency of this exceedingly important arm of the telegraph service would be alone an aim worth the best efforts and thought of telegraph engineers and executives. A return to the former or greater freedom from inductive disturbances would also vastly enhance the opportunities for the utilization of some of the readily available rapid automatic telegraph systems, which as previously intimated the introduction of night letter telegram service may render imperatively necessary in the very near future.

Returning briefly to a consideration of the matter of obtaining a permanent, non-inductive, non-retarding system of telegraph routes, it is clear that utilizing the suggested towers or reinforced concrete poles, with housed wires to afford mechanical protection against storms, incidently thereby guarding against undue variations of insulation resistance, (a great desideratum for numerous reasons) and by the proper selection of routes at a suitable distance from high-tension lines thus evading their disturbing inductive currents, an immediate improvement in the operation of circuits would be obtained. There would, however, still remain to be dealt with,

the detrimental effects due to the presence of conductors in underground cables leading into and out of cities and towns. This difficulty could, however, be obviated by placing the main operating departments of telegraph offices on the outskirts of such cities, from which offices loops might be run from duplex and quadruplex circuits to the various branch and brokers officers without detriment to the operation of the multiplex main circuits. All wires not required for the actual handling of traffic in a given town would in such cases enter the main operating room on the outskirts of the city and pass on without entering the city proper. In many small towns the telegraph lines following the highways enter at one end of the town and pass out at the other end, a custom that has frequently involved placing a comparatively large amount of cable in an unimportant locality considered from a telegraphic standpoint. By the plan suggested, only wires needed locally would enter the place by the shortest route to the business center, thereby minimizing the amount of cable required for the proper transaction of telegraph business at that point.

It is unnecessary here to comment on the economies and improvement of operation that could be rendered possible by even a partial adoption of the foregoing suggestions, further than to remark that a proper consideration of the subject will show them to be manifold and of great value.

It had been intended to include in this paper a general reference to recent improvements in the interior equipments of telegraph offices and also to describe the methods and materials now employed in aerial and underground telegraph cable work in this country, but owing to the brief time available for the preparation of the paper it has not been practicable to carry out that intention.

NOTE

The following paper is to be read at the 27th Annual Convention of the American Institute of Electrical Engineers in **Jefferson, N. H., June 28 – July 1, 1910.** This paper is to be presented under the auspices of the Railway Committee of the Institute. All those connected with the Institute and desiring to take part in the discussion of this paper may do so by being present at the meeting; or, if this is not possible, by sending in a written contribution.

Written contributions will be read at the meeting, time permitting, for which they are intended, either in full, in abstract, or as a part of a general statement giving a summary of the views of those taking the same position in the matter.

The principal object in getting out the paper in advance of the meeting is to enable and encourage those not in a position to attend the meetings to take part in the discussion by mail.

Contributions to the discussion of this paper should be mailed to **William McClellan, Chairman Railway Committee, 905 West Street Building, New York,** so that they will be received not later than June 23, 1910. Written contributions arriving within 30 days thereafter will be treated as if presented at the meeting.

(STORER AND EATON)

A paper to be presented at the 27th Annual Convention of the American Institute of Electrical Engineers, Jefferson, N. H., June 28–July 1, 1910.

THE DESIGN OF THE ELECTRIC LOCOMOTIVE

BY N. W. STORER AND G. M. EATON

The features to be embodied in an ideal electric locomotive depend entirely on the point of view. Any electric locomotive, however, must contain certain essential features.

First. Mechanical parts of strength sufficient for the required service;

Second. Motors of capacity sufficient to develop the required power;

Third. A reliable transmission system between the motors and driving wheels;

Fourth. Weight on driving wheels sufficient for adhesion;

Fifth. A complete control system;

Sixth. Riding qualities enabling the locomotive to negotiate the rails without undue damage.

More or less closely associated with these essentials there is an endless variety of detail concerning which no two men will hold identical opinions.

The electric locomotive designer must act as a clearing house for the opinions and ideals of all the men associated with railroad electrification. To prepare himself for this position, he must view the locomotive through the eyes of men connected with every branch of the service.

Locomotive Ideals. The man who is responsible for hauling trains on schedule time sees a perspective that does not include first cost, weight, or mechanical or electrical efficiency, as those terms are generally understood. He sees in the electric locomotive only a means for keeping his trains moving, and on schedule time. His conception of efficiency is represented by the number of trips made on schedule time, divided by the total number

of trips. He has had long, hard experience with steam locomotives, and is acquainted with their good and bad points. He accepts an electric locomotive only as a last resort, and then recommends the incorporation of as many as possible of the features of his successful steam locomotives. This on the face of it is a wise plan, but it should be remembered that a locomotive may be successful *because* of a given detail or it may be successful notwithstanding that particular feature. Again, a certain feature may be successful because of interrelation with other features, and a new design of locomotive must be carefully analyzed to see that an old and proven device will have the environment necessary for its best success. Too much emphasis cannot be laid on this point, as the differences in principle between steam and electric locomotives are not always easily recognizable. This point is well illustrated by fundamental differences in the application of cranks and connecting rods on steam and electric locomotives, which will be discussed in detail later.

The eyes of the motive power man see much the same features as those of the operating man, but his eyes magnify details of design in a greater degree. Both will wish to incorporate as many standard parts as can be used, and they will insist on the strength of all parts being ample to withstand every phase of the service such as bumping, speeding, overhauling, etc. They will be interested in the machine involving low maintenance charges, but in this respect they will not fully foresee the effect of the various mechanical features upon the electrical equipment, and they are liable to insist on the adoption of mechanical details, which of themselves have a low cost of maintenance, and yet at the same time will involve an excessive cost for the maintenance of the electrical equipment. Their ideal locomotive will operate safely at high speed, in either direction. It will be able to make up a reasonable amount of lost time, and will always be ready for service. It will not require long lay-overs, and will be in the shop the least possible time. They would like if possible a single type of locomotive which would perform any service that might be required of it, from making up and hauling a 2,500-ton freight train to making a high speed run with a "limited."

The amount of power consumed and the excessive weight involved in an interchangeable locomotive of this type are a matter of little importance to them, so long as the locomotive is strong enough to stand every phase of the service, and does not call forth protests from the maintenance-of-way

department and bridge engineers. They know that such protests will certainly be forthcoming if damage to track and bridges is greater than that attendant upon the operation of the accepted types of steam locomotives.

Up to within a short time it has been the accepted idea that an electric locomotive would have riding qualities greatly superior to those of the steam locomotive, and that it would cause much less track destruction, due to the perfect balance and the absence of reciprocating parts. Recent experience has demonstrated that these features in themselves are not sufficient to produce a good tracking locomotive, and it is now generally recognized that the proportioning of an electric locomotive which will have ideal riding qualities is one of the most serious problems today confronting the designer.

The ideal locomotive of the general manager or president of the railroad is one that will meet as nearly as possible the ideals of his subordinates, and in addition will be a part of that system which will give the most reliable service, consistent with a reasonable cost of operation; or, in other words, will earn the largest dividends on the investment. The cost of the locomotive will appeal most strongly to him.

It is popularly supposed that the ideals of the electrical engineer concerning electric locomotives embrace only the electrical details of the locomotive, such as motor design, efficiency, temperature, and the control and collecting system, but this is a mistake at the present time, whatever it may have been in the past. It is necessary for him to have the broadest possible ideal. It is his duty in connection with steam locomotive designers to select that combination of details which will be the best compromise of the ideals of all railway people. It must be recognized that every complete design is a compromise, as much so in locomotives as in other machinery, and as long as the ideals of the different departments are conflicting it is certain that an ideal locomotive, from all points of view, will never be secured.

Locomotive Problems

Transmission. At first sight it appears to be a very simple problem to transmit the power from rotating armatures to rotating wheels. This, however, is not the case, there being more or less serious objections and limitations to every type of transmission that has been proposed. Many of the types give excellent service when used in their proper places, but the fact

remains that for high speeds and also for maximum powers, the problem of transmission is one of the most serious among the mechanical problems confronting the designer.

It will be helpful to classify the various types of transmission. Some of the objections and limitations of these types will be discussed later:

a. Gearless motor with armature pressed onto driving axle. "New York Central." Fig. 1.

b. Gearless motor with armature carried on a quill surrounding axle, and driving the wheels through flexible connections. "New Haven Passenger." Fig. 2

c. Geared motor with bearings directly on axle and with nose

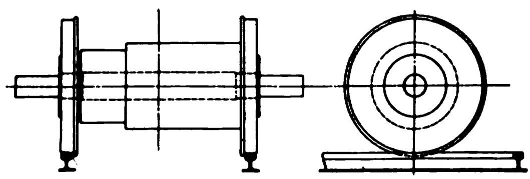


FIG. 1

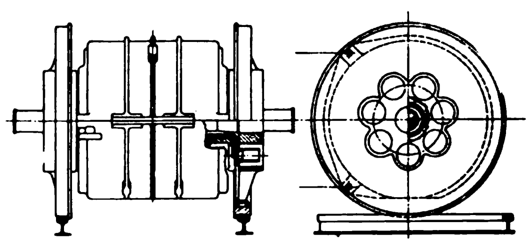


FIG. 2

supported on spring borne parts of locomotive. "St. Clair Tunnel." Fig. 3.

d. Geared motor with bearings on a quill surrounding axle, and (1) nose supported on spring borne parts of machine (New Haven Car Fig. 4) and (2) motor, rigidly bolted to spring-borne parts of machine, the quill having sufficient clearance for axle movements. "Four-motor New Haven Freight." Fig. 5.

e. Motor mounted rigidly on spring-borne parts, armature rotating at same rate as drivers, power transmitted to drivers through cranks, connecting rods and countershaft on level with driver axles. "Pennsylvania" Fig. 6.

f. Motor mounting and transmission as in (*e*) but motor

fitted with double bearings one part for centering motor crank axle and the other for centering the armature quill which surrounds and is flexible connected to the motor crank axle. "Two-motor New Haven Freight." Fig. 7.

g. Motors mounted on spring borne parts, armature rotating

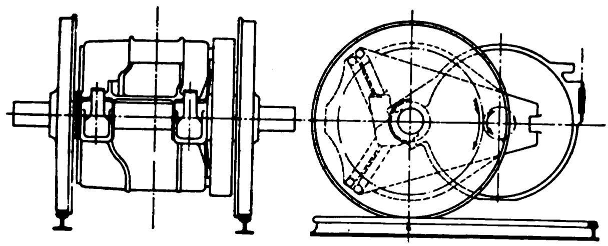


FIG. 3

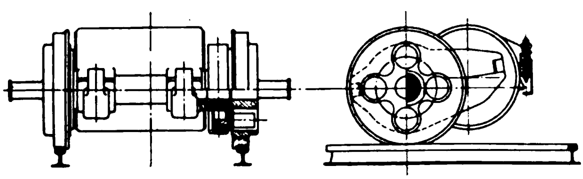


FIG 4

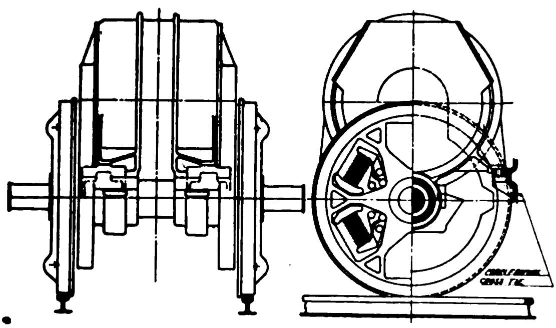


FIG. 5

at same rate as drivers, power transmitted to drivers through offset connecting rods and side rods. "Latest Simplon locomotives.", Fig. 8.

h. Motors mounted on spring-borne parts, armature rotating at same rate as drivers, power transmitted to drivers through Scotch yokes and side rods. "Valtellina Locomotives." Fig. 9.

j. Motors mounted rigidly on spring-borne parts, power transmitted through gears to counter-shaft, thence to drivers through Scotch yokes and side rods. Fig. 10.

Further classification of electric locomotives on the basis of framing and wheel arrangement is also of assistance in gaining a clear understanding of existing locomotives.

a. Cab and framing an integral structure. All weight carried on drivers. Drivers contained in a single rigid wheel base. "St. Clair Tunnel." Fig. 11.

b. Cab and truck framing separate structures, all weight carried on drivers. Drivers contained in two rigid wheel base trucks. Draw bar pull transmitted through center pins

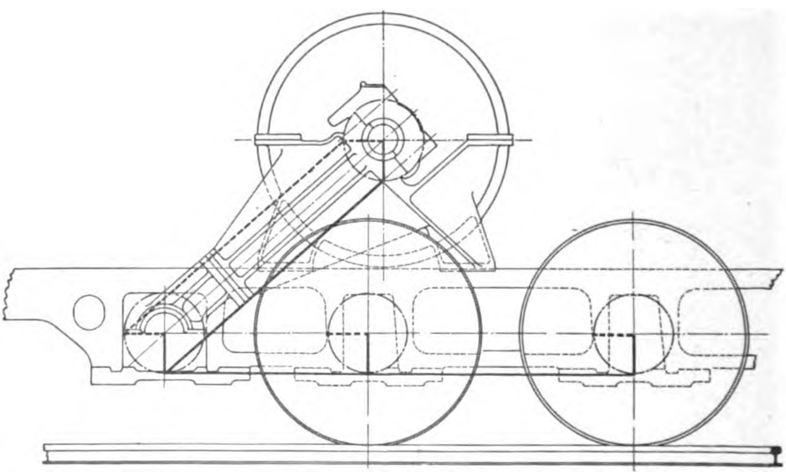


FIG. 6

or through truck frames. "Spokane & Inland Empire Ry. Co." Fig. 14. "P. R. R. 10001 and 10002."

c. Same as (*b*) but with added idle wheels for guiding and weight carrying. "Modified New Haven Passenger, and New Haven Freight." Fig. 15.

d. Any of the foregoing forms permanently coupled in pairs or articulated. "Pennsylvania." Fig. 16.

e. Same as (*a*) but with added idle wheels for guiding and weight carrying. "Valtellina or New York Central." Fig. 13.

f. Cab and framing an integral structure. All weight carried on drivers. Driver wheel base partly rigid and partly flexible. "Simplon Tunnel." Fig. 12.

Service Requirements. It has been stated that from an operating standpoint it would be very desirable to have one loco-

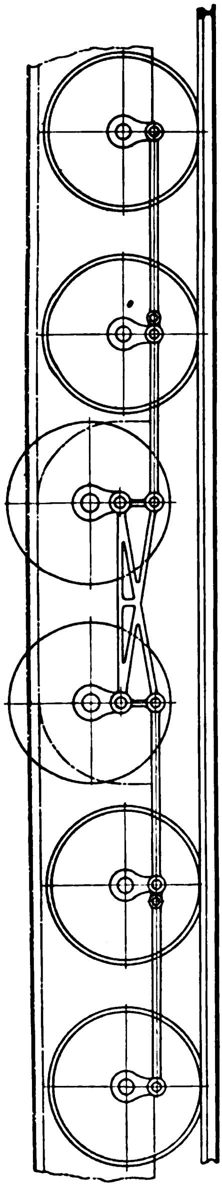


FIG. 8

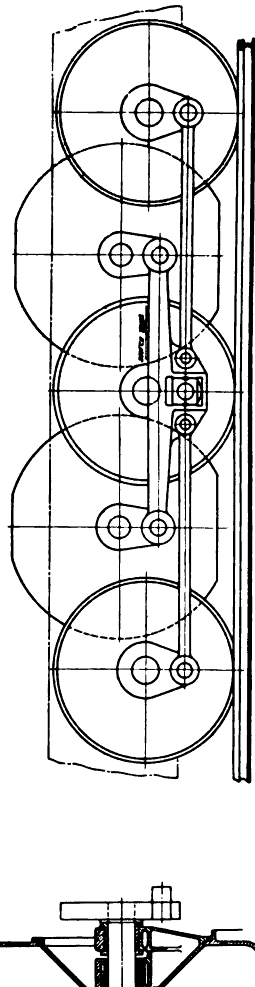


FIG. 9

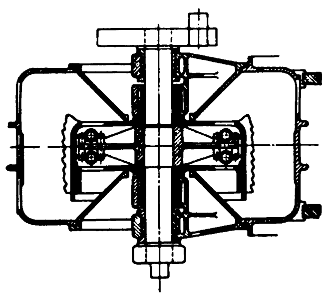


FIG. 7

motive which would be capable of handling at the desired speed any train from the heaviest freight to the fastest limited. While such a locomotive can be built, it will be a prohibitive cost.

It is commercially practicable to cover a considerable range of speed and weight of trailing load with one locomotive, and any passenger locomotive may be used to handle on its lower speeds freight trains within its capacity for tractive effort; but where the weights of trains to be handled and the speeds at which they operate vary as widely as they do on most trunk lines, an absolutely interchangeable locomotive is impracticable. This we believe will be shown in the discussion of the requirements for the various classes of service in the following pages.

Switching Service. From the nature of this service the locomotive operates to a great extent over the curves and special work. This track construction is expensive and hard to maintain. The locomotive should therefore embody primarily in its design such features as will enable it to negotiate this kind of track with the least effort. We list the chief of such features in approximately the order of their importance.

(*a*) Short rigid wheel base.

(*b*) Minimum dead weight per axle.

(*c*) Minimum total weight per axle needed for adhesion.

(*d*) Concentration of weight near midlength of locomotive, and short cab overhang.

(*e*) Effective equalization perferably of the three point type.

(*f*) Flexibility of framing under longitudinal twist to assist equalizing system.

(*g*) High center of gravity. While this is of helpful tendency it is probably not worth the expenditure of much money or weight on account of the slow speed of operation.

These features may all be summed up as those tending to produce a locomotive whose wheels may be deflected by the rails with the least attendant movement of the mass of the locomotive.

Fig. 17 illustrates a four-wheel steam switcher of a standard type. Attention is called to the extreme overhang and consequent nosing characteristic. This overhang is practically inherent in a steam locomotive of minimum wheel base.

Slow Freight Service.. Most of the transcontinental railroads are to day limited in their carrying capacity by long mountain grade divisions. The present practice is to run the heaviest freight trains that can be operated over these divisions. This service is now handled by consolidation or mallet steam engines, which haul 2,000 to 2,500 ton trains at 8 to 10 miles per hour, and electric locomotives are expected to handle the same or

heavier trains at higher speeds to increase the capacity on the line.

The latest developments in locomotive design indicate that the type of locomotive best suited for such service, with speeds of 12 to 15 miles per hour is one having a motor geared to each axle. The feature of prime importance in the design of these locomotives is the absence of weight in excess of that necessary for adhesion. Every ton of excess weight in the locomotive means a ton less trailing load. A slow-speed freight locomotive should be designed with all weight on the drivers.

In the slow-speed service, the maximum allowable weight per axle should be used if the total weight of locomotive can be thereby reduced. A greater dead weight per axle can probably

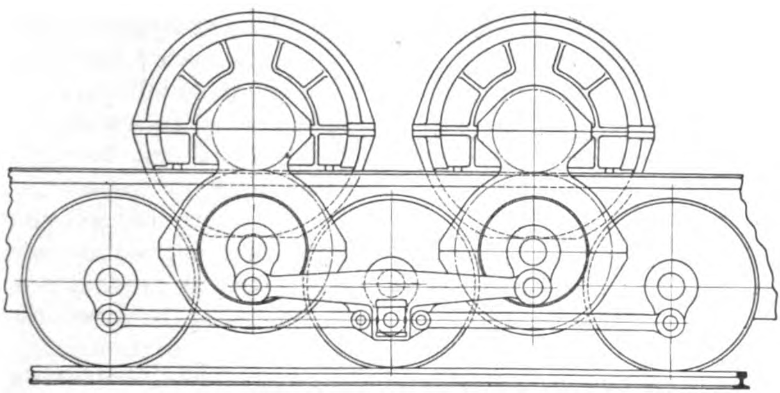


FIG. 10

be tolerated than is wise in switching service, because being a road engine, a much less amount of special work will be negotiated than in the case of a switch engine, and the damage to the track will not be excessive at the normal operating speeds.

If, however, complete spring support of the motors can be achieved without excess total weight, and this can usually be done, then the decrease in maintenance charges should much more than offset the increased first cost attendant upon such spring support.

There is a great difference of opinion among railway engineers both in regard to the total weight per axle and the amount of dead weight allowable. Some would keep the total weight per axle below 40,000 lb. and the amount of dead weight equal to that of wheels, axles and journal boxes. Others do not hesitate

to put 60,000 lb. on a single pair of wheels with a dead load of 15,000 to 18,000 lb.

The intention here is not to attempt placing strict limits on axle loads, but to call attention to general tendencies, as each actual installation must be settled upon its own merits, or in accordance with the practice on the particular line involved.

The wheel base of the slow-freight engine should be as flexible as possible so as to curve easily and prevent flange wear, and should take switches and turnouts without undue stress on the track. No idle leading or trailing truck axles will be necessary. The remarks on high center of gravity, equalization, concentration of weight at midlength of engine and flexible framing apply almost equally on switching and slow freight services.

Fast Freight Service. Some trunk lines have no heavy grades, and are able to operate their freight trains at speeds of 30 to 40 miles per hour, or even higher. For such roads a locomotive adapted to cover a range of speed from 30 to 60 miles per hour is well suited to handle both freight and all but the highest speed passenger trains.

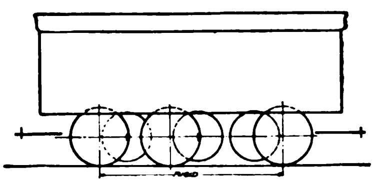


FIG. 11

Two points of departure from switching requirements are worthy of particular attention when the speed runs as high as 50 to 60 miles per hour. One is a requirement of service operation, and another is imposed by the design. These points are interesting in that service requirement and design limitation go hand in hand. First the speed makes it advisable to provide leading wheels of small size and light dead weight to assist in guiding and more particularly to iron the rails down gently to an actual bearing surface on the road bed and thus avoid the knock attendant on hammering the free rail down with the heavy drive wheel. Second, as the speed increases, either the tractive effort decreases with less weight required on drivers or the horse power demanded increases with attendant weight increase and the added wheels are necessary to avoid overloading the drive wheels.

High Speed Passenger Service. The most important requisite of a locomotive designed to operate at 60 miles per hour and over is its ability to run at the highest speeds possible without injury to the track. All the track disturbances mentioned above, except

in curves and special work, have been primarily in a vertical plane. When we consider speeds of 50 to 60 miles per hour, however, we are closely approaching the range where even on tangent track serious lateral disturbance is liable to occur. Extensive speed tests have shown that almost any kind of a machine will stay on the track at 40 miles per hour, without serious damage to tangent track. As the speeds increase above this figure, however, the bad riding qualities rapidly appear. The particular features following apply with more and more im-

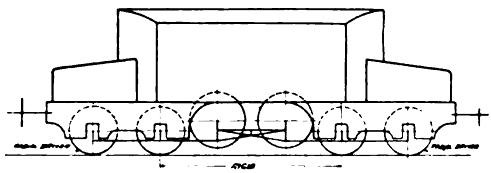


FIG. 12

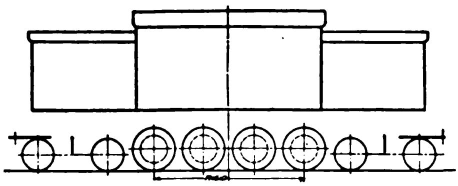


FIG. 13

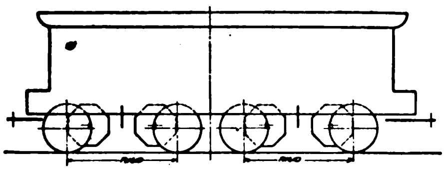


FIG. 14

portance as the speed increases so that we are led naturally to a consideration of the higher speed machines, bearing in mind again that no sharp dividing line exists and individual conditions must govern all concrete cases.

There are certain features that tend to reduce the intensity of the lateral forces on the track. First of these, and a source of much recent comment, is "high center of gravity." The acceptance of this as a cardinal principle of successful high speeding, however, is not universal. The theory on which the belief

in the value of a high center of gravity is based is that the higher the mass of the locomotive is placed above the axles, the less will be its restraining influence against lateral motion on the part of the wheels. The mass of the locomotive may take the general direction of the track while the wheels follow all the little irregularities in its surface and alignment.

Assume for instance, that a locomotive is running at high speed on tangent track and that some rail defect imposes sudden transverse movement upon the wheels. Under these conditions the mass of the wheels and axle and any other masses rigidly associated with them will deliver a shock approximating a hammer blow to the side of the rail head. Evidently therefore these masses should be minimized unless it can be shown

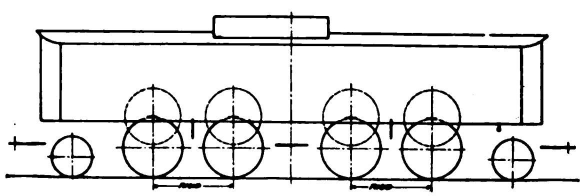


Fig. 15

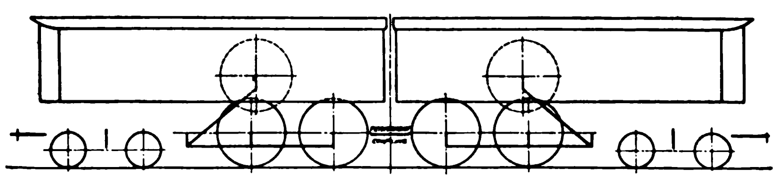


Fig. 16

that their increase does not involve serious injury to the track and consequent danger in operation.

The blow delivered by the spring borne parts of the locomotive is radically different from this in both low and high center of gravity machines. In the case of a locomotive whose center of gravity of spring borne parts is at the same height as the center of the transverse restraint, *i.e.*, about the center of the axle the transverse movement of the leading driver would impose a rotation of spring borne parts about a vertical axis. Fig. 19. The lateral force to impose such a movement would be very great, due to the great moment of inertia about this axis. In the case of a locomotive whose center of gravity is high above the center of transverse restraint the movement imposed upon the spring-

borne masses by transverse movement of the leading driver is a composite of two rotations, viz., about a vertical axis and about a horizontal axis parallel to the rails. Fig. 20. As the moment of inertia about the latter axis is much less than that about the former it is evident that the lateral forces involved in the high center of gravity machine will be less. The forces opposing rotation about horizontal axis are provided by the semi-elliptic riding springs, which will transmit their resultants ultimately to the running face of the rail and will not aggravate flange pressures. Were it not for the dampening effect of the friction

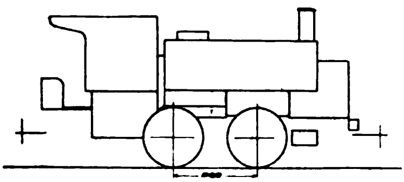
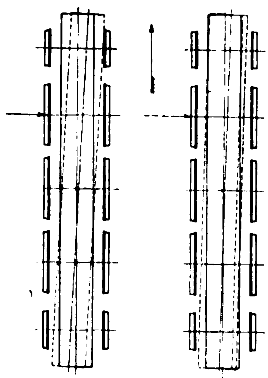


FIG. 17



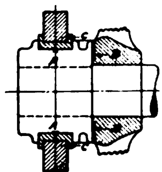


FIG 18

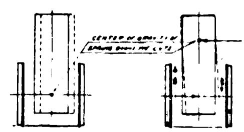


FIG. 19 FIG. 20

of the semi-elliptic springs and the detail friction of the machine, this rotation about a horizontal axis would be a simple harmonic vibration. The period and amplitude of this vibration would be functions of the characteristics of the semi-elliptic springs and of the polar moment of inertia of the masses moved.

Suppose for example that with the low center of gravity locomotive first considered, some combination of lateral springs were applied which would impose on the spring-borne weights a vibration about the vertical axis of period and amplitude and dampening action identical with that occurring on the high center of gravity machine. There being no rotation about the

horizontal axis, the forces required to control the vibration would be greater than with the high center of gravity machine, because of greater moment of inertia about the vertical axis; and further, the transverse rail stresses would be greater because the reactions of the controlling forces are transverse.

We can formulate an idea of the springs necessary for such transverse restraint by comparing them with the semi-elliptic riding springs which perform the dual function of supporting weight and resisting rotation about the horizontal axis. Probably transverse springs as heavy and with as great amplitude of motion as these semi-elliptic riding springs would be none too powerful to perform the required service, and it should be noted that their friction is almost as important as their spring action.

The foregoing discussion is predicated upon the assumption, that the spring borne masses are an integral unit; and it shows, from perhaps a new point of view, that the production of an

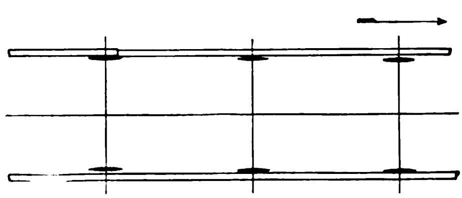


FIG. 21

ideal high-speed, low center of gravity engine of the type noted, while perhaps theoretically possible, is attended by serious if not insurmountable difficulties.

Considering further this horizontal rotation of the spring-borne masses of a locomotive with medium height of center gravity, we find that there is a zone that is neutral as regards transverse motion relative to the track. If in such a locomotive certain of the lower masses were hung from longitudinal trunnions located on the center line of the locomotive and in this neutral zone, it is evident that the rotation of the spring-borne masses would be more easily accomplished due to the lessening of the masses moved. Possibly gearless concentric motors could be hung in this way, in connection with a drive of sufficient flexibility to allow free wheel play.

This is not a combination that could be recommended solely because of good riding qualities. It is, however, entirely possible for such a machine to have sufficient attendant simplicity

to make it a better compromise than an engine where simplicity and mechanical efficiency are directly sacrificed to secure high center of gravity.

It may be mentioned that the New Haven locomotives have a motor mounting that approximates this condition. There is not as great amplitude of springs to allow unrestrained wheel play either vertically or laterally as might be desired, but there is enough to cushion all blows that the track receives from the mass of the motors, and the reports of track maintenance since the addition of the leading wheels eliminated the nosing tendency, are very gratifying.

Almost equally advantageous with the high center of gravity is the concentration of the mass of the locomotive about this center of gravity, both vertically and longitudinally. It is conceivable that if the mass of the locomotive could be so concentrated longitudinally about the center of gravity as to decrease

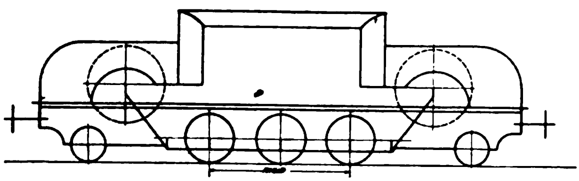


FIG. 22

the radius of gyration about the vertical axis to a value well within the rigid wheel base, there would be no more serious lateral disturbance on the track with a low center of gravity machine than with one having higher center of gravity but with a much longer radius of gyration about the vertical axis. Every effort should, therefore, be made to locate the mass of the heavy parts of the locomotive as near the middle as possible.

The action of a low center of gravity locomotive can be very materially improved by locating the point of side restraint below the level of the driving axles. Every inch that this point is lowered is equivalent to raising the center of gravity of the spring-borne parts by an equal amount.

Wheel Sizes. On a steam locomotive, large wheels are considered essential for high speed service. The primary reasons are to minimize the wear and tear on parts subjected to reciprocating stresses, to maintain the piston speed at a safe figure, and to keep down the blow on the track due to the in-

correct counterbalance. An advantage of large wheels in any high speed engine lies in the attendant low surface speed of the journal, and again in the long time elapsing between tire turnings. There is also less distress of metal in both tire and rail, due to the greater area of contact with the large wheel. On the question of the advantage of large wheels for road engines, there is probably a greater unanimity of opinion among railway men than on any other detail of the equipment.

Equalization. The most successful high-speed steam locomotives of to-day are designed with a three-point equalization, having one point ahead and two trailing. This is apparently a very desirable arrangement for any locomotive, and the electric locomotive designer is at once confronted with a new problem in adapting it to a locomotive which must be designed to operate equally well in either direction. The only means by which the actual three-point equalization can be secured on such an engine is to devise some means for shifting the equalization when the engine is reversed. It is possible to arrange air cylinders interlocked to the reverse lever, which will automatically alter the equalization system, so that a single point of equalization will always lead and two-points will always trail. This should, however, be reserved for a last resort, as it does not seem wise to accept such weight and complication unless it proves essential.

A symmetrical arrangement of wheels on the two ends of the locomotive has been criticised by some as lending itself to a nosing tendency in high-speed engines. While there is some evidence to support such contention, it is not regarded as absolutely proven, and there is an open question as to whether the symmetry of equalization rather than symmetry of wheel arrangement is not the irritating cause.

Whatever system of equalization is used, it is very desirable that the springs on an electric locomotive should be very flexible. This in itself will tend to equalize the loads on the drivers without the complete three-point equalization system. It is contended by some of the best engineers that a four-point equalization system with flexible springs is better than the three-point equalization system.

Interchangeable Locomotives. If the accuracy of the foregoing outline of features for various services is accepted, the impracticability of performing all classes of service economically with a single machine, is at once made apparent. The engine for the heavy high speed passenger train will require motors of

large capacity. This capacity, however, can be utilized only at the high speeds with a corresponding low tractive effort. The electric locomotive is not so well suited for interchangeable service as the steam locomotive because of the fact that its continuous tractive effort is practically constant regardless of the speed at which it is operated. A steam locomotive, on the other hand, can develop its maximum horse power at almost any speed, and its continuous tractive effort may be anything from its maximum, which is developed at starting, down to that necessary to give its maximum horse power at its maximum speed. An electric locomotive designed to develop its continuous capacity at 60 miles per hour, if operated in freight service at 30 miles per hour will be developing only one-half of its capacity. On account of the necessity of having the best riding qualities at high speed, the locomotive will be very much heavier than one designed especially for freight service having the same continuous tractive effort. The cost also will be much greater. It may be contended that where gearless motors are used, it is simply a matter of winding the motor to develop a given tractive effort at its maximum speed, and it will then be suitable for any service requiring this tractive effort at lower speeds. This is true, but for mechanical reasons the converse is not true; namely, that a freight locomotive can be operated in passenger service by winding the motors for a higher speed. An economical mechanical design for a locomotive, which is thoroughly satisfactory for freight service, will not be at all suitable for the high speed passenger service. Steam locomotives have been used interchangeably to some extent in railway service, but in general this has been found impracticable.

Transmission from Motor to Wheel. At the beginning of the paper it was stated that the transmission of power from the motor to the driving wheels is one of the most serious problems confronting the designer. It is closely allied with the type of framing, wheel base, and location of center of gravity of the locomotive. While many types of transmission are in successful operation, none is above criticism from some point of view.

Gearless Concentric Motors. It is well known that gearless motors in which the armature is carried dead on the axle while having the simplest transmission of all are destructive to roadbed when operated at high speeds. The mounting of the motor on a quill driving the wheels through springs is also objectionable from some standpoints, but it is open to less objection from the

fact that its weight is all spring-supported against both vertical and lateral shocks.

There is a definite, though somewhat restricted, field where the gearless concentric motor is most successful. High service speed is essential to allow a rate of revolution sufficient to secure an economical power output per unit weight of motor. The gearless concentric motor for slow-speed operation cannot compete with the geared motor, as the weight and cost will be prohibitive. The power demanded per axle must not be so great as to result in wheel overloads.

Transmission Through Gears

Gears are very unpopular in many quarters, and have unquestionably some disadvantages. However, there is probably no part of the standard street car motor equipment which has given less trouble than the gears and pinions. There have been many cases of broken gears and of gears that have had an unduly short life, but all of these cases could be traced to a cause or causes which are now well understood, and can easily be avoided.

We feel perfectly safe in saying that, in the present state of the art, gears can be designed which will perform satisfactorily in any class of railway service. The improvements which have been made in the quality of gears and pinions by the use of high-grade materials having greater strength, higher elastic limits, and improved wearing qualities, are such that there should be no hesitancy on the part of the locomotive designer in recommending gears for service where a reduction from the armature speed is desirable, as in low-speed locomotives.

Gears for very slow-speed work may be pressed on the driving axle as in ordinary street car work. Where the motors are of large capacity, it will be necessary to use twin gears, as in the case of the locomotives for the Cascade Tunnel, and the high-speed freight locomotive No. 071 for the New York, New Haven & Hartford, R. R. The former has the gears pressed directly on the axle, but in the latter, the gears are mounted on quills. This latter design is much to be preferred, and is in fact necessary where the locomotives are to be operated at speeds much above 30 miles per hour. The use of the quill, of course, involves a further connection between the quill and the driving wheels. This is accomplished in the case of the New Haven locomotive by long helical springs, one end of which is clamped to a projec-

tion from the quill and the other to the spoke of the driving wheels. These springs have such a large amplitude of motion that the axle is almost entirely unrestrained by the motor which is mounted rigidly on the truck framing. On this locomotive the gears are also provided with a spring connection between the rim of the gear and the center, which removes practically all of the shock due to high pitch line speed, and at the same time divides the load equally between the two gears on the quill.

A further advantage of gearing the motor to a quill having large clearance around the axle is that it enables the motor to be mounted rigidly on the truck, and directly above the axle, thus permitting the greatest economy of space by bringing the driving axles close together. It also raises the center of gravity of the spring-borne parts and brings the motor well above the dust and dirt of the roadbed. And as the motor projects through the floor into the cab, the commutator, brushes and oil boxes are rendered accessible at all times. It also facilitates the use of forced ventilation which greatly increases the capacity of motors of the enclosed type. The limitations of this type of transmission are not yet well defined, as it has been in use but a short time, but the performance thus far has been so satisfactory as to give promise of its success in a wide range of application. It is believed that on account of the extreme flexibility of the drive that the pitch line speed may be raised to a much higher value than has ever before been deemed possible. The flexibility effectually prevents the extreme shocks which are ordinarily received by the gear teeth of a high speed locomotive when the gear is pressed directly on the axle.

The use of gearing which permits the armature to run at a higher speed of rotation than the driving axle, places a limit on the speed of the locomotive which from the point of view of the operating man may be undesirable. It is necessary in designing such a locomotive to consider the maximum speed at which the locomotive is to be operated and leave a margin above this figure before the safe limit of the armature speed is reached. The service conditions will determine the maximum locomotive speed and also the speed at which the motors should develop their continuous rating horse power. These two locomotive speeds and the limiting peripheral speed of the armature, together with the desired horse power output form the mechanical basis for the motor design. For economical designs it is not advisable to allow a maximum armature speed of more than

2 or 2.5 times the continuous rating speed. If a greater ratio than this is required, the armature speed must be reduced. The weight and cost of motor for a given continuous capacity will increase directly with this ratio.

Some of the other limits in a geared motor design are the pressure per inch width of gear face at the continuous rating, and the directly associated limit of the available distance between wheels, which must be divided between the gears and the motor. The available gear reduction is limited, on the one hand, by the diametral pitch necessary to secure a tooth with sufficient strength or life, together with the minimum number of teeth in the pinion consistent with low maintenance; and on the other hand, by the maximum number of teeth in the gear that can be applied with a given diameter of driving wheel with sufficient rail clearance.

With theoretically perfect gears a very high pitch line speed should be operative. In regular interurban mounting of motors, heavy strains are imposed on gear teeth in high speed operation by sudden vertical displacement of wheels due to track irregularities, with attendant acceleration or retardation of armature. In such applications a maximum pitch-line speed of 3,500 to 4,000 ft. per minute is operative. With complete spring support of motor and flexible connection to wheels, or with flexible gears, it is evident that a higher speed will be permissible. There are insufficient data at hand to approximate the limit under these conditions.

The above statements are all based on the use of spur gears and it is confidently expected that even better results can be obtained by the use of helical gears which are now coming into use. The success of this type of gear which is used for the Melville-McAlpin steam turbine drive indicates a sphere of usefulness for gears which has scarcely been touched.

While it is too early in the use of gears for large locomotives, to make an absolute statement of fact in regard to the allowable pressures, experience thus far indicates a pressure of 1,000 lb. per inch width of gear face as a perfectly practicable value for continuous rating of large gears. With special steel pinions and high grade gears it is probably safe to exceed this figure. It is well known that for short hauls pressures far above 1,000 lb. per inch are now in daily successful operation. In the locomotives for the St. Clair Tunnel, for instance, the pressure is carried on a single gear having a 6-in. width of face. The normal loads

at which the locomotive operates on the up-grade give a pressure of from 1,500 to 2,000 lb. per inch width of face on the gears. With this pressure the pinions have a life of 40,000 to 50,000 miles, and none of the gears has yet worn out, although the locomotives have been in continuous operation for over two years. With twin gears there is a possibility of further increase in unit pressure as the absence of relative skewing of pinion and gear shafts produces a better application of the tooth load.

Probably the greatest limitation to the use of motors geared to the axles or to quills surrounding the axles is the restricted space between the wheels. As the output of the motor increases the width of the gear face must increase also, and this extra gear space must be deducted from the space ordinarily occupied by the motor. This results in motors having a larger diameter than would ordinarily be designed. In spite of this limitation, however, it is probable that geared motors as large as 500 h.p. continuous rating will be used. This is about as great an output as can be utilized on a single axle.

Transmission by Side Rods

A desire to secure the good riding qualities of the high-speed steam locomotive, and at the same time to avoid the difficulties and limitations imposed by mounting the motor concentric with the axle, has lead to the adoption of side rods for transmitting the power from the motor to the wheels. There is a very strong tendency in this direction both in Europe and in this country. The general form universally adopted except for the three phase locomotives in Italy and Switzerland, which will be discussed separately, is that of the now familiar Pennsylvania locomotive which is illustrated by Fig. 6. The motor is mounted on top of the locomotive framing, and the armature shaft connected by quartered cranks to a jack-shaft located in the same plane as the driving axles. The power is transmitted from the jack-shaft to the wheels by other parallel rods.

This type possesses some very distinct advantages. It permits the use of a single powerful motor to drive two axles. The motor is mounted in the cab instead of under it so that all parts are readily accessible and are thoroughly protected from the dust, dirt and water from the road bed. The location of the heavy motor so high in the cab raises the center of gravity of the locomotive to a height corresponding to that of high-speed

steam locomotives. The side rods form a transmission system that is familiar to all steam locomotive operators. It apparently has all the good points of the steam locomotive rods and is, in addition, susceptible of perfect mechanical balance and gives a uniform tractive effort.

There are, however, certain fundamental differences between the performances of side rods on steam and electric locomotives.

1. The steam locomotive transforms the heat energy of the steam into mechanical work by means of a reciprocating engine. Connecting rods and cranks are therefore essential features. The electric locomotive on the other hand develops its power by rotation and no single type of transmission can be listed as indispensable.

2. In case of a steam locomotive there are at least two independent sources of mechanical forces, viz., the cylinders. Each piston constitutes a "free end" of the transmission system. The distance from the center of cylinder to the center of main driver axle is not a hard and fast value, as a slight variation means only a change of crosshead overrun and of cylinder clearances. In an electric locomotive where there is a single motor, crank and rod connected to a countershaft, there are no "free ends" to the system. For this reason great accuracy of tram and parallelism of motor shaft and countershaft are essential, any error being accompanied by serious stresses in the transmission with associated low mechanical efficiency and high maintenance charge, especially for bearing brasses.

3. In the steam engine the stresses on the transmission system at any point in the cycle can be very closely approximated by means of indicator cards taken from the cylinder, together with centrifugal stresses. In other words, each side of the engine can be considered separately. With the electric locomotive on the other hand, there is but one source of mechanical force; viz., the motor which exerts a constant turning moment or torque throughout the entire revolution. This constant torque must be transmitted to the driving axle without modification except for the losses in bearings. At certain points in the cycle all the torque of the motors is transmitted through one crank; at certain other points it is transmitted through the opposite crank. At intermediate points it may or may not be transmitted through a single crank, as the interchange of work is different in different machines, being a composite function of journal and pin clearances together with bending and torsional

deflections of all elements of the transmission and framing. It is therefore not possible to analyze the forces on one side of the locomotive independently of the other side.

4. In the steam locomotive the main rod connects the cross head to the drive wheels. In the electric, all the driving effort is transmitted through four running pins in series before any useful work is performed. This results in considerable loss of mechanical efficiency. It may be noted that the use of knuckle pins would avoid one or possibly two of the running pins mentioned but thus far no railway operator has been found in this country who is willing to accept knuckle pins in an electric locomotive. Knuckle pins have caused so much trouble from breakage that they will have to be modified considerably before they will be acceptable. The trouble seems to lie in the twisting of the rods due to uneven track.

The side rod type of locomotive is at a disadvantage when compared with the high-speed geared type described, because of the fact that the mechanical parts of the locomotive and also the motor frames must necessarily be much heavier to withstand the reciprocating stresses imposed on them. They will also require much more careful work in assembling and will therefore be more expensive. On the other hand, it would seem that after the side-rod locomotive is once completed, the mechanical parts should be very cheap to maintain. The results of the operation of the Pennsylvania locomotives will be awaited with great interest.

Scotch Yoke Side Rod Type

The type of drive which has been used to the greatest extent with the three-phase locomotives in Italy is that illustrated in Fig. 9, utilizing the so-called "Scotch Yoke" for connecting the motors with the driving wheels. This has been in use for several years and has apparently given excellent results. In these machines much of the criticism attendant upon connecting rod applications has been obviated. The motors, being flexibly attached to the spring-borne parts, are not subject to severe cranking strains and can therefore be made light mechanically. The motor shafts, it is true, should line and tram accurately but they are so located that this can be done with minimum difficulty. The mechanical parts also can be made considerably lighter because of the fact that there is no jack-shaft required, and the cranking strains are taken directly on the armature

shafts which are supported in bearings in the side frames. The design, however, sacrifices high center of gravity, and some alternate plan for securing easy riding qualities must be adopted. One which has been suggested utilizes a plan somewhat in line with that suggested for the gearless concentric motors; namely having springs between the motor and side frames for cushioning lateral shocks. The mechanical efficiency of this type should be higher than that of the rod-connected design, because of the fact that the power is not transmitted through so many running pins. It has the objectionable feature of a sliding connection between the driving yoke and the pin on the middle driving wheel, but this apparently causes no trouble whatever. In fact, the locomotives as observed on the Valtellina Railway operate smoothly, and apparently with small friction loss. This may be ascribed in part to the fact that all bearings are kept flooded with oil. The use of knuckle pins for transmitting power from the "Scotch Yoke" to the outer driving wheels is made perfectly safe by the use of spherical pins or spherical bearings.

This type of drive will give probably a lighter locomotive than is possible with any other drive having motors operating at the same speed as the driving axles. It has thus far not met with favor in this country, but its merits will undoubtedly bring it into use for moderate speed work where gearless motors are desired.

Combination Gear and Connecting Rod Drive.

Where slower speeds are desired than can be secured by the use of motors operating at the same speed as the axles it is sometimes more economical to use two motors geared to jackshafts and connected to the drivers by means of the "Scotch Yoke" in the same way as just described. Fig. 10. This scheme has some advantageous features which are not at first apparent. It permits the use of large motors and gives much greater space for them than can be secured between the drive wheels where the motors are geared either to the axles or to quills surrounding the axles. The motor is mounted so that its center of gravity is high, and as it extends through the floor into the cab, the bearings and brushes are easily accessible. In this respect the motor has all of the advantages possessed by the rod-connected motor. Gears can be located outside of the driving wheel so that they can be replaced without dismantling the locomotive any further than

required by the removal of the side rods. Locomotives involving this priciple have been built in Europe, and a large one is now under construction for the Midi Railway in France. As stated before, it is especially fitted for work where it is desirable to reduce the number of motors to a minimum and at the same time operate at slow speeds with heavy tractive efforts.

This locomotive, however, is subject to such criticism as is involved in synchronous revolution of many parts with a consequent loss in efficiency and with possible inertia complications. In this respect it is practically on a par with all rod-connected locomotives.

Rod-Connected Locomotive With Radial Axle

A description of the principal types of transmission would scarcely be complete without mention of the three-phase locomotives now in use in the Simplon Tunnel. These locomotives have been described in the technical press. The chief point of interest lies in the location of the motors, the connection to the drivers, and in the radial driving wheels at the ends of the locomotive. The motors are located as close together at the middle of the locomotive as possible, and their crank pins are connected together by a frame. From pins on this frame on a line with the center of the axles, rods are carried to the nearest driving wheels, and thence other rods connected to the axles of the outer drivers, there being four pairs of driving wheels. It is, of course, essential where side rods are used that all axles should remain substantially parallel, and in order to secure the radial motion of the wheels at the ends of the locomotives, it is necessary to mount the wheels on quills which surround the axles and connect them together only at the middle point by a kind of universal joint. By these means the wheels are able to move in a radial direction, while the axles which drive them are kept parallel to the inside driving axles. This seems to be operating very satisfactorily, and with some modifications will probably meet other conditions where all the weight is carried on the drivers, and a rigid frame locomotive with flexible wheel base is required.

Conclusion

The foregoing survey is incomplete, as the possible combinations of locomotive framing, motors, and transmission between motors and drivers are almost limitless, and it would be impossible in a paper of reasonable length to discuss even those that are

well-known. The aim has been to present the problem as viewed by the authors, and to discuss a few of the fundamental principles on which the design of the locomotive should be based.

The problem is in a word: To design a locomotive incorporating all essential features, and as many non-essential but desirable features as possible, and for a price that will make electrification attractive to railway officials.

An address delivered at the 249th meeting of the American Institute of Electrical Engineers, New York, May 17, 1910.

THE INTERNATIONAL ELECTRICAL UNITS 1893-1910.

BY E. B. ROSA

Secretary of the International Committee on Electrical Units and Standards.

The Chicago Electrical Congress of 1893 adopted definitions and numerical values for the electrical units, which were recommended to all countries with the hope that they would be generally accepted and that international uniformity would result. The following year they were adopted in this country by an act of Congress, which is still in force. England adopted them also in 1894, and France in 1896. In 1898 Germany adopted somewhat different definitions for the fundamental electrical units, taking the same numerical values for the ohm and ampere, but a different value, based on the results of further experiments, for the Clark standard cells, in terms of which the volt is expressed. In some other countries the value of the Clark cell, which had been adopted by America, England and France (1.434 volts at 15 deg. cent.) was chosen, and in others the value adopted by Germany (1.4328 volts at 15 deg. cent.) was taken. Hence there were two different values for the volt.

In course of time, the method of preparation of the Clark cell was improved so that it became more reliable, but at the same time its electromotive force was slightly altered. At the Bureau of Standards an allowance was made for the change, so as to preserve the volt as nearly as possible unaltered. In some other countries, however, the original numerical value was retained, notwithstanding the new cells had slightly different values from the old. The result was that an appreciable discrepancy arose between the values of the volt in use in America and in some other countries that were nominally on the same

basis. Hence there were and still are three different volts in use in different countries. The Weston Normal cell, adopted at the London Conference of 1908, in place of the Clark cell, has the following official values: In America, 1.0189 volts at 25 deg. cent., equivalent to 1.019125 at 20 deg.; in Germany, 1.0186 volts at 20 deg.; in England, 1.0184 volts at 20 deg. Some of the other countries use the same value as America, others the same as Germany. The National Physical Laboratory provisionally adopted the last named value only one year ago, and no other country, as far as known, has followed its example.

It may be thought that these differences, which at most amount to only a tenth of a volt in 150 volts, are trifling, and that their importance has been greatly magnified.

Such small differences are, however, very important in these days of accurate physical measurements. For example, when standardized incandescent lamps have been taken from the Bureau of Standards to the national laboratories of Germany, England and France for the purpose of comparing our photometric units with theirs, we have been obliged to call attention to the difference in the volt in the different countries in order to insure that there should be the same current flowing through the lamps in each laboratory. It is not enough to specify the voltage and current of the lamps, but they must be given in triplicate in the units of each country. Clearly, this is a condition that can not be permitted to continue.

The Chamber of Delegates of the St. Louis Congress, in 1904, passed resolutions recommending the formation of an International Electrical Commission for the purpose of securing international uniformity respecting electrical units. The following year, in October, 1905, a preliminary conference (representing six countries)[1] was called by the Physikalisch-Technische Reichsanstalt, at Charlottenburg, to consider the questions that should properly come before an international electrical congress, and to come to an understanding as to the decisions to be desired from it. The Chicago Congress of 1893 had fixed the values of all three units entering in Ohm's law, namely, the ohm, the ampere and the volt. It was found later that the values chosen were inconsistent, and for that reason Germany adopted a dif-

1. Invitations to this conference were sent to the following persons: Dr. S. W. Stratbon and Prof. H. G. Carhart, America; Dr. R. T. Glazebrook and Lord Rayleigh, England; Prof. E. Mascort, France; Prof. Victor von Lang, Austria; Prof. Eric Gerard, Belgium; Prof. Dr. F. Kohlrausch, Germany.

ferent and more accurate value for the volt. To guard against a repetition of this embarrassment, it was agreed at the Charlottenburg Conference that only two of the three units should be fixed independently, the third being determined from the other two. Thus, as the precision of measurement increased, the numerical value of the third could be easily altered if necessary. The Charlottenburg Conference agreed further that the ohm and the ampere should be the two units to be definitely fixed as had been done in Germany seven years previously, and that the volt should be the derived unit. It was further agreed that an international conference ought not to decide differently from the program laid out at Charlottenburg without previously calling together another informal conference like that at Charlottenburg for a preliminary discussion.[2] The Bureau of Standards was not represented at the Charlottenburg Conference, although an invitation had been sent to the Director. He sent however a written communication favoring the choice of the ohm and the volt as the two independent units. The reason for this preference was that the two fundamental standards which are actually employed in electrical measurements are standards of resistance and standard cells. Both are concrete, they can be verified, transported, and

2. The following resolutions and opinions were formally adopted by the Conference:

The conference expresses the wish that an International Convention should be summoned in order to arrive at agreement in the electric standards which are in use in the different countries.

The following resolution was further adopted:

In view of the fact that the Laws of the different countries in relation to Electrical Units are not in complete agreement, the Conference holds it desirable that an official conference should be summoned in the *course of a year* with the object of bringing about this agreement.

The Conference further expresses the opinion:

1. That the information before it is not sufficient to enable it to propose any alteration in the formerly accepted value for the ampere.

2. That the information before it is not sufficient to enable it to lay down exact directions in respect to the silver voltameter and the standard cell.

3. That if a proposal for a change in the accepted value of the ampere is to be brought from any source before a formal Congress to be held later, an agreement in writing on the point should be come to previously between the parties interested. If differences of opinion in the matter cannot be removed, a new preliminary conference should be held.

The same procedure should be observed in regard to the specification for the silver voltameter and the standard cell, in the event of such specifications being submitted to a formal conference from any quarter.

used directly in precision measurements. On the other hand, the silver voltameter in terms of which the ampere is legally defined, is not properly a standard of current. There is no such thing as a concrete standard ampere. The silver voltameter, or more correctly the silver coulometer, as Professor Richards proposed to call it, records the total quantity of electricity that has passed through the instrument. To obtain this an elaborate experiment is involved, by means of which the mean value of the current is derived from the weight of silver deposited and the time the current flows. Whereas standards of resistance and standard cells can be quickly and conveniently compared with one another with a precision of one part in a million, and can be transported and recompared for the purpose of international comparisons, silver voltameters can only be compared accurately by means of elaborate and lengthy investigations, and are wholly unsuited for practical use in precise measurements. Prof. Carhart also urged these objections in a carefully prepared paper which he presented at the Charlottenburg Conference. These objections to the ampere as the second fundamental unit were urged by the American delegates to the International Electrical Conference, which was called by Great Britain, and which met in London in 1908, as they had been urged by the American representative and the Bureau of Standards in 1905. It was further pointed out at London that the Weston Normal cell had been much developed in the three years intervening between the Charlottenburg and London Conferences, and its reproductibility had been greatly improved. The mean value of a group of such cells prepared at the Bureau of Standards and taken to London in October, 1908, differed from a group that had been set up at the National Physical Laboratory by less than one thousandth of one per cent, and agreed with cells from the Reichsanstalt and the Laboratoire Central nearly as well. Almost identical specifications for the Weston cell were used in all four laboratories, and there was good reason to believe that the volt could be maintained constant to one or two parts in 100,000 by means of the Weston cell as then made.

Notwithstanding these powerful arguments, which seemed to the delegates from America and France to be overwhelming, the Congress under the leadership of England and Germany, adopted resolutions in accord with the program outlined at the preliminary conference at Charlottenburg three years before,

fixing the ohm and the ampere as the two independent electrical units, the former in terms of the resistance of a specified column of mercury, and the latter in terms of the amount of silver deposited in the silver voltameter. The numerical values in both cases were to be left exactly as fixed at the Chicago Congress of 1893. No agreement could be reached at London as to the exact specifications of the silver voltameter, nor as to the value of the Weston Normal cell which was adopted in place of the Clark cell as the standard of electromotive force. The Conference decided that the ohm should be the same as before, the ampere should be the current which should deposit 1.11800 milligrams of silver per second in a voltameter which was not definitely specified, and that the Weston Normal cell should have such an electromotive force as to be consistent with the ohm and the ill-defined ampere. This would be about 1.0184 volts at 20 deg. cent., but this value was only suggested as provisional. Hence, when the Conference adjourned, international uniformity had not been attained, and the international ampere and the international volt were two very hazily defined quantities.

However, the London Conference prepared the way for international agreement by establishing an International Committee on Electrical Units and Standards, which was authorized to complete the work of the Conference and to carry on intercomparisons of standards among different countries, and to promote investigations upon the subject of electrical units and standards, to the end of securing international uniformity and of obtaining electrical standards of the highest possible accuracy. It was recognized that in an international congress, representing all the civilized countries of the world, a majority of the countries not having national laboratories, and perhaps a majority of the delegates of diplomatic rather than scientific training, it was impossible to consider properly the questions involved in the determination of electrical units and standards, and hence the only satisfactory method of procedure would be to provide for a continuous body which could study the questions fully, carry on international comparisons, and secure that degree of precision and uniformity which the importance of the electrical industries and the present day development of the science demanded.

This committee represents eleven different countries, there being two members each from America, England, France and Germany, and one member each from Austria, Italy, Russia, Switzerland, Holland, Belgium and Japan. The president of

the committee is Professor Dr. E. Warburg, president of the Reichsanstalt, Berlin; vice-president, Dr. R. T. Glazebrook, director of the National Physical Laboratory, London; treasurer, Professor S. W. Stratton, director of the Bureau of Standards; secretary, Professor E. B. Rosa, physicist of the Bureau of Standards. The other eleven members of the committee are as follows: Dr. Osuke Asano, Department of Communications, Tokyo, Japan; M. Rene Benoit, Bureau International, Sevres, France; Dr. N. Egeroff, director, General Chamber of Weights and Measures, St. Petersburg, Russia; Professor Eric Gerard, Liege, Belgium; Professor H. Haga, Groningen, Holland; Dr. Ludwig Kusminsky, Commission of Weights and Measures, Vienna, Austria; Dr. Stephen Lindeck, Physikalisch-Technische Reichsanstalt, Berlin, Germany; Professor Gabriel Lippmann, The Sorbonne, Paris; Professor Antonio Roiti, Florence, Italy; Mr. A. P. Trotter, Electrical Standards Laboratory, Whitehall, London; Professor H. F. Weber, Zurich, Switzerland.

In addition to the fifteen members appointed by the International Electrical Conference, the committee was authorized to elect associate members to assist in carrying on its work, and at its first meeting in London, following the conference, five associate members were elected as follows: Dr. W. Jaeger, of Berlin; Mr. F. E. Smith, of London; Professor Paul Janet, of Paris; Professor H. S. Carhart, of Ann Arbor, Michigan, and Dr. F. A. Wolff, of the Bureau of Standards, Washington.

The first work before the new International Committee was to secure uniformity throughout the world in the value of the volt. The number 1.0184 volts at 20 deg. cent. had been adopted provisionally at the London Conference, and the easiest thing to do was for America to follow the example of the National Physical Laboratory and adopt this figure and urge other countries to do the same. We were confident that we could maintain our volt constant by means of the Weston Normal cell as now prepared, and the completion of the specifications for the silver voltameter might be postponed indefinitely, so far as electrical measurements were concerned, for as had been pointed out at the conferences of 1905 and 1908 the standard cell was superior to the silver voltameter with respect to accuracy and reproductibility. Such a course was not only the easiest, but it could be defended on other grounds, for the differences of opinion and experience regarding the silver voltameter a year ago was such that it was impossible to agree on specifications or on numerical values.

However, to do that would have been to nullify the decision of the London Conference by making in effect the volt the second independent unit, the ampere being derived from the ohm and the volt; that is, to obtain by indirection what the American representatives urged at the Charlottenburg and London Conferences should be done directly. This we were unwilling to do. We came back from London disappointed with the work of the Conference, but nevertheless loyal to its decisions. We accepted the definitions and numerical values there chosen as final, and set to work in good faith to carry them into effect. Obviously the only thing to do was to investigate the silver voltameter with great thoroughness, and when the facts should be fully developed, agreement on specifications and the value of the standard cell would doubtless be possible. In this spirit the investigation was diligently pursued at the Bureau of Standards, taking advantage of work done elsewhere, especially of that done by the gentlemen who are present here to-night[3] as representatives of three European standardizing institutions.

It has been found that mercury ohms may be prepared so accurately to specifications that the mean value given by a group of tubes from a number of fillings and measurements will be in agreement with another group of mercury ohms set up and measured with equal care to within two or three parts in 100,000. Probably the mean of several such groups, representing several national standardizing laboratories, will by the help of sealed wire standards permit the unit of resistance to be maintained constant, to within one part in 100,000 for an indefinite period.

As has been stated, Weston Normal cells as set up during the past few years in different laboratories agree remarkably in value. We believe that if new cells are set up at least once a year, to the same specifications, that the mean of any group of twelve or more cells will agree with any other group to within one or two parts in 100,000 at the worst. Hence, in order that the ohm and the silver voltameter may together serve to fix the value of the standard cell and also serve as a reliable check from time to time on its value, it is desirable that the sum of the errors or uncertainties of the two shall not exceed one or two parts in a 100,000. Thus, it appears at once that unless the silver voltameter be reproducible to an extraordinary degree, the periodic checks on the constancy and reliability of the Weston Normal

3. Messrs. Jaeger, LaPorte and Smith, the European delegates to the Washington joint investigation.

cell will be useless. To control the cell by a standard less reliable than itself is worse than not to control it at all. It therefore appeared necessary to bring the silver voltameter up to the highest degree of accuracy and reproducibility possible, before attempting to complete the official specifications or to decide on the value of the standard cell. After a quarter of a century of investigation since the classical work of Rayleigh, in the early eighties, at the hands of eminent investigators, both physicists and chemists, in Germany, France, Holland, England, and America, in which scores of papers have been published, the silver voltameter seemed to us one year ago to be a greater mystery than ever. It had been urged at the London Conference that it was simpler and better understood than the standard cell. When measurements are made only to a fiftieth of one per cent, the silver voltameter may be considered a simple and well known instrument. But when the precision of measuring the current and time, and of washing and weighing the deposits are increased tenfold, and one takes account of all disturbances, chemical and physical, which may affect the weight by as much as one part in a hundred thousand, the silver voltameter presents possibilities of complications undreamed of by investigators of a few years ago.

After getting a glimpse of the difficulties to be met, and yet satisfied that they could be overcome, the American members of the International Committee on Electrical Units and Standards proposed that a joint international investigation to clear up, as far as possible, outstanding problems on the standard cell and the silver voltameter be arranged with representatives of several of the national standardizing laboratories as participants. Professor S. W. Stratton in his capacity as director of the Bureau of Standards offered the facilities of the Bureau of Standards for an international investigation, and in his capacity as treasurer of the International Committee on Electrical Units and Standards offered to secure the funds to pay the expenses of the investigation. The proposal was received with favor by the members of the International Committee, and the formal approval of the Committee was obtained by ballot. In this connection the Treasurer received valuable assistance from Mr. John W. Lieb, Jr., who placed the matter before the governing bodies of the American Institute of Electrical Engineers, the National Electric Light Association, the Association of Edison Illuminating Companies and the Illuminating Engineering Society. These

four societies made appropriations of $500 each to defray the expenses of the proposed investigation. Their generosity in this matter is very highly appreciated by the International Committee on Electrical Units and Standards. Some smaller contributions were also received.

It was arranged that the proposed investigations should be carried out at the Bureau of Standards by representatives of that institution together with one delegate from the Physikalisch Technische Reichsanstalt, Berlin, one from the National Physical Laboratory, London, and one from the Laboratoire Central d'Electricite, Paris, The European delegates, as appointed by the directors of the three above named institutions, are Professor W. Jaeger, Mr. F. E. Smith and Professor F. Laporte. These gentlemen have had a very considerable experience in work with standards of resistance, standard cells and silver voltameters, have published various investigations on the same, and are eminently qualified to represent their respective institutions and to join in the work of research and deliberation upon the various questions that will arise during their stay in Washington. The representatives of the Bureau of Standards are Professor E. B. Rosa and Dr. F. A. Wolff. In addition to published papers, a great deal of experimental work has been done at the Bureau of Standards, in the last two years, which is not yet published, and which has thrown considerable light upon the questions at issue.

The date first set for the investigation was October 1, 1909, but in order to give the various participants further time for preparation it was deferred until April 1, 1910. Much progress was made in the investigation of the silver voltameter in the year which elapsed between the first proposal of the joint research and the assembly of the delegates, yet there were many unsettled questions yet remaining to be investigated when they came together.

The European delegates brought with them from their own laboratories a quantity of apparatus and chemicals in order that they might reproduce at the Bureau of Standards work done in their own laboratories as accurately as possible. In addition to the work on the silver voltameter, which forms the principal part of the work to be done, standard cells brought together from the various laboratories are being compared and new cells are being set up, each laboratory being represented by cells set up from materials from all four laboratories. Standards of re-

sistance are also being accurately compared. These comparisons will permit a value to be assigned to each set of resistances in terms of the mean international ohm, and similarly for the standard cells. Fortunately, the differences in resistance standards and Weston Normal cells, as already intimated, are extremely small.

I cannot give any account of the progress of the investigations which have been under way at the Bureau of Standards since the first of April more than to say that the work has been pushed energetically, and even enthusiastically, not only by the delegates themselves but by the six or eight members of the scientific staff of the Bureau who are assisting in the work. Great progress has been made, and we are confidently expecting that the outcome will fully justify the time and money expended. As is often the case, the by-products of the investigation are proving of great value. Not only do we expect to solve the problem immediately set before us, of providing specifications which will permit fixing the Weston cell with the necessary accuracy, but a substantial addition will be made to our knowledge of the chemistry of silver nitrate, and to the subject of electrolysis.

On behalf of the International Committee on Electrical Units and Standards, under whose auspices the investigation is conducted, and to which a full report of the results will be transmitted, I wish to express our appreciation and thanks to the four societies which so generously provided the funds for the expenses of the delegates, to the gentlemen here in New York who have so kindly received and entertained the delegates from abroad, and to the delegates themselves for the trouble they have taken in coming so far to assist in the undertaking, and for the able and enthusiastic manner in which they have entered into the work. I sincerely hope that this is only one of a series of such international coöperative enterprises in which we shall come to know each other better in working together for the solution of scientific problems of common interest.

A paper presented at the 27th Annual Convention of the American Institute of Electrical Engineers, Jefferson, N. H., June 28–July 1, 1910.

CONSERVATION OF WATER POWERS

PRESIDENTS ADDRESS

BY LEWIS B. STILLWELL.

The conference of governors, which assembled at the White House, in May, 1908, in response to an invitation extended by President Roosevelt, focused the attention of the American people upon a subject which all recognize as one of fundamental national importance and one which appeals to the engineering profession with all the force which comes from special knowledge. True conservation of our natural resources means wise utilization of those resources without unnecessary waste. Such utilization of materials used in construction and of energy is the primary and essential business of the engineer. Since the days of Smeaton and of Watt, the engineer has been building the lighthouses of material prosperity and releasing and directing for the common welfare, those vast forces of nature imprisoned and overlooked for centuries but now utilized on a scale which dwarfs the physical powers of man to insignificance.

During the last 25 years, a period practically coterminus with the life of this Institute to date, the art of transmitting power by electricity has grown from a laboratory experiment into a development universally recognized as one of the great factors of industrial and commercial life.

The latest publication of the United States Geological Survey, relative to this subject, estimates the aggregate water powers of the United States at minimum flow to be 36,000,000 horse power and the aggregate which presumably can be developed on the basis of six months' flow per annum at not less than 67,000,000 horse power.

A very large proportion of the water powers hitherto unappropriated are either located upon government lands or are

dependent, wholly or in part, upon the run-off from government lands.

The regulations established by national and state governments which control or affect the further utilization of water powers, therefore, are of peculiar concern to the members of this Institute. A bill endorsed by the administration is now before Congress which, if passed, will confer definitely upon the President and his executive assistants full authority in respect of withdrawal of public lands and unappropriated water powers. Probably the bill will pass and if so we may expect that the question of governmental machinery and methods for handling practically this highly complex and vitally important subject will be raised in acute form.

If the views of the engineering profession are to be effective, either in moulding public opinion or in assisting the legislative and executive representatives of our people, by supplying facts essential to correct generalizations and deductions, it is important that those views be clearly stated at the right time and that apparent lack of agreement among those best qualified to measure the practical results of existing or proposed governmental regulations should not destroy their influence.

The present occasion seems opportune for the presentation of a brief and non-technical discussion of the practical bearing and effect of existing laws governing the appropriation of water powers located on public lands, which, as now construed and applied, are seriously retarding the utilization of these powers.

To those who realize the vast possibilities of a far-sighted and thoroughly scientific development and utilization of our water power resources, particularly those of the Rocky Mountains and the Sierras, no subject can be more interesting. Present practice, whether ideal or faulty, is more likely to be modified than revolutionized, and now is the time for unprejudiced and candid discussion of the regulations now in force.

(1) The Relation of Forests and Stream Flow

The Bureau of Forestry has established regulations governing the appropriation of water powers located on streams which drain watersheds included in whole or in part in Forest Reserves. Among these regulations is the imposition of a graduated rental, to be paid by the individual or corporation appropriating the water power and used by the government for forest purposes. This rental rests upon the assumption that the appropriator of

the power will be benefited by the preservation of the forest, and this idea is accepted generally by engineers and by the public.

Mr. Gifford Pinchot, Chief Forester at the time when the present regulations were established, states his understanding of the physical facts upon which this charge is based in a document explaining the policy of the Forest Service, as follows:

> The National Forests include the great mountain chains of the west. The rain and melting snow of these ranges feed the mountain streams. The forest cover on the steep slopes acts like a mighty sponge, absorbing the excess of rainfall in the wet season and giving it out to the thirsty lands in the dry season. It is for the express purpose of thus 'securing favorable conditions of water flows' (Acts. June 4, 1897) that Congress has authorized the creation of national forests and expends money for their administration and maintenance. Where the forest cover is destroyed by reckless lumbering and the fires which inevitably follow, the rains immediately run off the steep slopes as from the roof of a house, producing destructive floods in the valleys and leaving no store of water for the dry season. Therefore, when a power company puts its plant on national forest land, it gets from the government two things which it ought to pay for, *viz.*, (*a*) The use of lands of great value for power purposes, for the steep mountain sides give the fall which is essential for a power plant; (*b*) the guarantee of a steady flow of water as an incident to the land occupied by the plant. This steady flow is also essential to a power plant.

During the last two years, the question of the actual or assumed effect of forests on the watershed in regulating the run-off, has been widely debated. That forest cover controls the run-off to a material extent has been vigorously asserted by engineers prominent in the government service and by many others, and on the other hand, it has been seriously questioned by a number of our leading engineers, notably by Col. Chittenden, in a paper read before the American Society of Civil Engineers, in March, 1909, and by Dr. Willis L. Moore, Chief of the United States Weather Bureau, in a report addressed to the Committee on Agriculture, of the House of Representatives, in 1910, entitled "A Report on the Influence of Forests on Climate and on Floods."

I do not propose to enter into a detailed discussion of this complex subject at this time. Col. Chittenden's paper and its discussion, as printed in the Transactions of the American Society of Civil Engineers, have covered the subject perhaps substantially as well as it can be covered by applying the inductive method to existing records.

The report of Dr. Moore and the article on "Floods", in Water Supply Paper No. 234, prepared by the United States

Geological Survey, also debated the subject at great length, the radical difference of opinion between these two gentlemen being due apparently in large degree, to the fact that Dr. Moore is considering total annual run-off, while Mr. Leighton is investigating the relation of "flood tendency" to precipitation.

As Dr. George F. Swain pointed out in a recent discussion of this subject at Boston, the difficulty in reaching an agreement along the lines adopted in the papers referred to results from the fact that all of these gentlemen are applying the inductive method of reasoning to a subject so complex and so varied as practically to preclude the possibility of general agreement in the inferences drawn. The physical laws which govern the phenomena under discussion are all well known, and to the scientist the deductive method of dealing with this subject is not only easier but is more convincing than the attempt to draw conclusions from incomplete records of precipitation and stream flow where even approximate knowledge of the extent to which the surface of the watershed in question is forested, or plowed, or covered by vegetation other than forest, is not available.

Such reasoning unquestionably leads to the conclusion that the preservation of forests on the watershed does to a greater or less extent regulate and control not the aggregate annual run-off but the rate at which that run-off varies during the year, and this idea is accepted generally by engineers and by the public. It is also accepted apparently by the majority of engineers who have discussed this subject in our various engineering publications, using the inductive method in drawing their conclusions.

As the essential physical facts which bear directly upon forest control of run-off, and consequently upon the relation of forested watersheds and water power, the following as stated by Dr. Moore may be accepted probably without material error:

(1) Precipitation controls forestation, but forestation has little or no effect upon precipitation.

(2) Any local modification of temperature and humidity caused by the presence or absence of forest covering the buildings of villages and cities etc., could not extend upward more than a few hundred feet, and in this stratum of air saturation rarely occurs, even during rainfall, whereas precipitation is the result of conditions that exist at such altitudes as not to be controlled or affected by the small thermal irregularities of the surface air.

(3) During the period of accurate observations, the total annual pre-

cipitation has not increased or decreased to an extent worthy of consideration.

(4) The total annual run-off of our rivers is not affected materially by any other factor than precipitation.

(5) There is no adequate evidence to justify the conclusion that extreme floods in recent years attain higher stages than formerly.

Other conclusions stated by Dr. Moore in the report above referred to the author is not prepared to accept, and as regards that forest control which is practically related to the commercial value of water powers, he believes the following to be a correct statement:

While the aggregate annual run-off of our rivers in general depends upon the total annual precipitation, the presence of forest cover on the watershed regulates the rate of run-off to an extent which in many cases materially affects the value of the water power, this regulation tending to equalize the flow and prolong it during the dry season.

With this understanding of the essential physical facts which are pertinent it is proposed in this paper (1) to discuss briefly certain provisions included in the present regulations of the Forest Service governing the appropriation of water powers dependent in whole or in part upon forest reserves, and (2) to suggest the outline of a plan which to the author appears preferable to that now in force.

The present form of permit provides a nominal charge (rental) for the land occupied by power house, dam, canals, penstocks, flumes, etc., the rate being "One dollar per acre and Five dollars per mile for the land occupied by said works". It provides also that "the gross operation charge for any year shall be calculated by the forester upon the basis of the quantity of electric energy generated in such year at a maximum rate, which shall not exceed the following amounts per thousand kilowatt hours:

For the 1st year	2	cents
" 2nd "	4	"
" 3rd "	6	"
" 4th "	8	"
" 5th "	10½	"
" 6th to 10th years, inclusive	12½	"
" 11th " 15th " "	15	"
" 16th " 20th " "	17½	"
" 21st " 25th " "	20	"
" 26th " 30th " "	22½	"
" 31st " 35th " "	25	"
" 36th " 40th " "	27½	"
" 41st " 45th " "	30	"
" 46th " 50th " "	32½	"

The foregoing are maximum rates applicable only in cases where all the water utilized comes from the Forest Reserve and the entire head developed results from the topography of the forest: In all other cases, deductions are made as follows:

' From the gross operation charge for any year calculated as above:

(*a*) A sum bearing approximately the same ratio to one-half of such gross operation charge as the area of unreserved land on the watershed bears to the total area of the watershed as of the beginning of each year.

(*b*) A sum bearing approximately the same ratio to one-half of such gross operation charge as the length of conduit outside the Forest Reserve bears to the total length of such conduit as of the beginning of each year.

(*c*) A sum bearing approximately the same ratio to the balance remaining after said deductions " a " and " b " as the quantity of electric energy generated from water stored artificially by the permittee over and above what is generated by the natural flow, bears to all electric energy generated.

The sum remaining after all the aforesaid deductions have been made constitutes the net operation charge for such year.

The rationale of the deduction for water stored artificially by the permittee is obvious. That for the first two deductions described is stated in an informal explanatory document of the Forest Service, as follows:

Since the two advantages furnished by the Government are the maintenance of a steady flow from the forested watershed, and the fall resulting from the topography of the forest, one-half of the conservation charge is calculated as based upon each of these advantages. Therefore:

(*a*) if a part of the watershed which supplies the power plant is outside of the national forest, the one-half of the conservation charge calculated upon the advantage resulting from the maintenance of the steady flow by the conservation of the forest cover is reduced proportionately and (*b*) if a part of the fall which the permittee is to use in developing power is outside of the national forest, the one-half of the charge which is based upon the fall is reduced proportionately.

THE IMPOSED RATES AS A TAX ON POWER ENTERPRISES

The proposed conservation charge, at least during the early years of the contract, cannot be regarded reasonably as constituting any very serious financial burden imposed upon the individual or corporation developing the water power. If power be sold at an average price of one cent per kilowatt hour, the maximum conservation charge during the first five years of operation is equivalent to a tax of 0.61 per cent of gross receipts. During the next five-year period, it is increased to 1.25 per cent of gross receipts and it increases gradually from this figure to a maximum of 3.25 per cent of gross receipts, which rate applies

during the last five years of the 50-year life of the contract. The average charge during the fifty-year period is 2.086 per cent of gross receipts, if power be sold at the price assumed, *viz.*, one cent per kilowatt-hour.

If power be sold at an average price of 0.5 cent per kilowatt-hour the average conservation charge during the period of the lease becomes 4.172 per cent of gross receipts, and the maximum, which applies during the last five years of the lease, is 6.5 per cent of gross receipts.

It is a fair question, however, whether a more rational method, and one which in certain important respects would tend to produce better results, might not be devised. The plan in force obviously is open to several objections. Among these are:

(1) The imposition of a tax upon output means that the man who installs a highly efficient plant is called upon to pay a higher conservation charge than the man who wastes water by the installation of a cheap and inefficient plant. The effect of the conservation charge in influencing type of construction, and consequent effective utilization of the water, will probably be small but unquestionably that influence is exerted in the wrong direction:

(2) The proposed method of charging imposes a heavier burden upon the man who sells his power at a low price than upon him who sells it at a high price. The tax measured in percentage of gross receipts, is obviously twice as high in the case of the man who sells power at an average price of 0.5 cent per kilowatt-hour as it is in the case of a man who sells power at an average price of one cent per kilowatt-hour.

Both of these objections were pointed out in a paper read by Mr. F. G. Baum, before the American Institute of Electrical Engineers, at Atlantic City, N. J., in 1908, but the writer has not heard them referred to since, and they deserve careful consideration.

(3) Mr. Baum also calls attention to the fact that under the plan proposed by the Forest Service " the man who takes his power to a market, say one hundred to three hundred miles away must pay to the Government for the losses incurred in doing so and pays more than the man who sells to the home market. The man who reaches out with his power is equalizing conditions, just as railroads equalize conditions by their transportation facilities ".

The Italian law, recognizing this point, reduces the rental

in the case of transmitted power. The basis of this reduction, as stated by M. Rene Tavernier, Chief Engineer, Department of Public Works, Republic of France, in his valuable article on "The Public Utility of Water Powers and their Government Regulation" (Water Supply Paper No. 238) is as follows:

> For power transmitted by means of electricity to distances greater than 10 kilometers (about 8 miles) there is granted upon the annual rental of 3 francs per horse power, a reduction calculated by multiplying the square of the distance expressed in kilometers by a fixed coefficient of 0.001. In no case shall the rental be reduced to less than one-half of 1 franc per horse power.
>
> Under this formula the minimum reduction, that is to 0.50 franc, will be attained in transmission over 50 kilometers (about 31 miles).

While the method of applying the "conservation charge" has been criticised in many quarters and while the objections above pointed out are valid, the method in force possesses undoubted advantage in the fact that it is definite and readily determined by reference to records which the permittee can easily keep. The charges moreover are adjusted to encourage development of the water powers by recognizing the fact that few, if any, can earn interest on the necessary investment from the start. In enterprises of this kind, the cost per unit of output generally decreases as the output increases. The forest service charge, recognizing this fact, is made small at the start and increases gradually. Except by reducing the average charge for the period, it would be difficult to devise a plan less onerous for the permittee.

(4) While the imposed charge could not be regarded as excessive, if the power developed were entirely, or even very largely, dependent upon the preservation of forest cover upon the watershed, it represents a high rate when measured in comparison with the increase in commercial value of the power, which, under ordinary conditions, is due to the forest. If, for illustration, it be assumed that under average conditions "forest control" adds 25 per cent to the value of the water power, a tax averaging 4.172 per cent of gross receipts is a tax of 20.86 per cent of the gross value contributed by the forest.

(5) The tax is imposed upon power from all "forest reserve lands," regardless of the actual condition of the forest upon which it is based. Obviously, therefore, a uniform tax must be very much heavier in some cases than in others, as compared with the benefit upon which it theoretically rests.

(6) It tends to retard utilization of water powers and stimu-

lates the use of coal for power purposes—a result which is in direct contravention of the primary object of conservation.

(7) Something less than one-half the public domain is included within the limits of the forest reserves. To secure maximum revenue and to minimize the average retarding effect upon utilization of these water powers resulting from a system of rental, any charges which may be imposed by the Federal Government upon water power appropriation should apply to all public lands.

The author has expressed the opinion that the imposed charge would not be regarded as excessive if the power developed were entirely, or even very largely dependent upon the preservation of forest cover upon the watershed. In his judgment, however, that effect has been very greatly exaggerated by the majority of writers who have endeavored to instruct the public regarding the subject.

To sustain the announced theory of the Forest Service, it is evident that the value of the water power should be directly dependent upon forest control of the run-off. Obviously the statement that " the forest cover on the steep slopes acts like a giant sponge, absorbing the excess of rainfall in the wet season and giving it out to the thirsty lands in the dry season " and that the " power company which puts its plant on national forest land gets from the Government the guarantee of a steady flow of water " are highly figurative.

The extent to which forest cover and other surface conditions which tend to regulate run-off, succeed in equalizing stream flow, is illustrated in the following tabulated statement, showing in the case of ten (10) fairly representative rivers of the Atlantic and Pacific slopes the maximum, average and minimum run-off in second feet per square mile for periods of five consecutive years and the minimum run-off expressed (*a*) in percentage of maximum run-off and (*b*) in percentage of average run-off.

Without attempting to discuss the complex conditions which determine the relations of maximum, average and minimum run-off, it is evident that in no case does existing forest cover or any other surface condition effectively equalize the flow.

As regards the relation of minimum to maximum run-off, the most favorable case, that of the Merrimac river, shows a minimum flow of 1.86 per cent of the maximum, while for the ten rivers the minimum flow averaged is 0.837 of the maximum flow averaged. As regards the relation of minimum to average

run-off, the most favorable case, the Yadkin, shows 17.6 per cent while the average of the ten (10) rivers is 9.95 per cent.

The effect of forest cover in adding to the commercial value of a water power, results from two facts, namely, first, the fact that an increase in minimum run-off reduces the necessary in-

FIVE YEAR RUN-OFF TABLE

River	Gauging station	Drainage area sq. miles	Maximum run-off sec. ft. per sq. mile	Average run-off sec. ft. per sq. mile	Minimum run-off sec. ft. per sq. mile	Minimum in per cent of Max.	Minimum in per cent of Ave.
Kennebec......	Waterville, Me.	4380	17.5	1.96	0.0388	0.222	1.98
Merrimac.....	Franklin Junction, N. H.	1460	16.93	1.998	0.315	1.86	15.77
Connecticut....	Holyoke, Mass.	8144	14.12	1.623	0.258	1.83	15.9
Susquehanna...	Binghamton, N. Y.	2400	19.62	2.044	0.0187	0.095	0.916
Yadkin........	Wilkesboro, N. C.	500	36.8	2.446	0.43	1.17	17.6
Savannah......	Augusta, Ga.	7294	18.83	1.56	0.198	1.05	12.7
Black Warrior.	Near Cordova Ala.	1900	26.0	1.515	0.01473	0.0567	9.73
Feather.......	Oroville, Cal.	3640	29.0	2.354	0.33	1.14	14.0
Yakima.......	Near Yakima, Wash.	3300	19.37	1.322	0.1926	0.995	14.56
Naches........	Near North Yakima, Wash.	1120	19.55	1.489	0.0268	0.137	1.8
			21.772	1.8311	0.18226	0.837	9.95

vestment in auxiliary steam or other power plant; second, the fact that some portion of the flood waters, which otherwise would flow past the power plant, at a time when the water available exceeds the amount needed, is held back long enough to permit its commercial utilization. As regards the first of the two conditions referred to, if we assume that auxiliary steam power is

used to insure a continuous supply equal to the average which a given head on each of these rivers can develop, it will be seen that such auxiliary plants must be capable of producing power in an amount ranging from 82 per cent to 98 per cent of the water power. The difference, therefore, between the best and the worst case among these typical streams affects the cost of the auxiliary plant to the extent of 16 per cent of the cost of a steam plant capable of developing the same output as the water power.

As regards the effect of forest cover upon the relative proportions of energy output from the water power and from the auxiliary steam plant, the conditions are so complex as to prevent profitable generalization. The holding back of a portion of the flood waters saves fuel and other operating costs of the auxiliary steam plant or reduces the artificial storage required. While it is evident that this effect, under the best conditions existing upon any of the watersheds, drained by the streams referred to in the table, is not such as to justify the theory that the forest is the principal factor affecting the value of the water power, the author would not be justified, from present knowledge, in attempting to fix its average effect upon that value.

Features of the Present Regulations which should be Changed

Permit Non-Transferable (*Clause* 15).

Clause 15 of the power agreement now in force reads as follows: "The permit here applied for shall be non-transferable (U. S Revised Statutes, Section 3737) and shall be subject to all prior valid claims which are not by law subject thereto".

The aim in view of course is to avoid monopoly, as a result of which an artificial price might be maintained higher than the average which would be fixed by competition of similar developments in the same market.

If effective, it is obvious that this requirement must retard development. The economic reasons which demand that water powers on the same stream should deliver their output to the same network of distributing circuits in many cases are material, and those which demand that the output of developments on different streams should be similarly combined are even more weighty. In the former case, under certain conditions, as has been pointed out by Mr. W. S. Lee, in his paper before the American Institute of Electrical Engineers, (PROCEEDINGS for

April, 1910), the net output of a stream effective for commercial purposes may be considerably increased. In the latter case, owing to the fact that the relative run-off of neighboring water-sheds sometimes varies widely during successive years, the reliability of the supply of power to the user is materially increased by combination. To put the matter another way, if combination be not permitted the aggregate investment in auxiliary steam plants or gas engine plants must be largely increased, which obviously is bad economy and means an increase in cost of power not only to the producer but also to the user.

By electrically combining the output of a considerable number of water powers, interruptions of service, due to accidents to flumes, or to transmission circuits, are decreased.

The clause, in my judgment, should be modified by permitting transfer, subject to approval by the government. The right of a state or municipality to fix charges, in the case of a public utility company selling its product within the limits of such state or municipality, has been established by decisions of the Supreme Court of the United States. The danger that American communities in general, knowing this fact, will submit for any great length of time to the imposition of rates that are really extortionate, is not comparable to the economic loss which is certain to result from the imposition of conditions limiting the opportunity for profitable investment of capital. In this connection it is evident that even an assumed water power monopoly of the largest conceivable size must sell its power at a cost lower than the cost of competing power produced by steam plants.

The established right of a state or municipality to fix rates at which power is sold is an absolute protection applicable by local governments best able to judge the conditions which determine what is an equitable charge.

Continuous Operation of Plant.

Clause 18 reads as follows:

> The permittee shall, except when prevented by the act of God or the public enemy, or by unavoidable accidents or contingencies, continuously operate for the generation of electric energy, the works to be constructed under the permit hereby applied for, in such manner as to generate after such generation begins, not less than the following percentages of the full hydraulic capacity of the said works measured in kilowatt hours: in the first year . . . per cent; in the second year . . . per cent; in the third year . . . per cent; in the fourth year . . . per cent; in the fifth year . . . per cent; and in every year thereafter . . . per cent.

The object in view is to prevent a power company increasing its prices by creating an artificial power famine and to secure full utilization of the available power. Some permits have specified that not less than twenty-five per cent of the full hydraulic capacity, measured in kilowatt hours, must be generated; others as much as seventy-five per cent, depending upon special circumstances supposed to govern the case.

In many cases this clause presents serious difficulty to the power company. In the majority of instances with which the writer has been personally familiar, it has been extremely difficult, if not impossible, to predict either maximum or minimum limits of the growth of power output. Circumstances may be conceived under which a power company, operating not only the plant covered by the permit but also other plants, might shut down the first named to produce temporarily an artificial scarcity of power, but the fact that this would mean an idle investment would make this a rare case. If it be necessary to retain such a clause, it should be accompanied by a provision permitting, with the consent of the government, a reduction in the percentages originally fixed.

While discretionary power to make conditions upon which capital has been invested more onerous will retard or prevent development, the bestowal upon a Secretary of Agriculture or a Secretary of the Interior, of power to make those conditions less onerous involves no corresponding public risk, since that Secretary would destroy himself politically who should grant such authorization without proper cause. No power company can afford to invest capital under a contract which leaves it in the power of a government official to increase the burdens of the enterprise within the term covered by the permit, but the government and the public can well afford to bestow upon a responsible official authority to reduce those burdens upon proper application and presentation of valid reasons.

Term of Permit

Clause 20 of the permit in force reads as follows:

"The permit hereby applied for shall cease and be void, upon the expiration of fifty years from the date of approval hereof, but it may then be renewed in the discretion of the duly authorized officer or agent of the United States, and upon such conditions as he may in his discretion fix: *Provided* that such officer or agent, in fixing such conditions shall consider the actual value at that time for power and all other purposes of the lines and rights of way within National Forests occupied and used under the permit hereby applied for and the actual value at that time of all

improvements lawfully made by the permittee within National Forests under the permit hereby applied for, but neither the property of the permittee, if any, outside of National Forests, nor the permit, franchises, bonds, capital stock or other securities of the permittee shall be considered in fixing such conditions."

It will be noted that this clause contains no provision for taking care of the contracts which may be in force between the permittee (or his successor) and his customers at the expiration of the fifty-year period, nor does the author find any provision covering this point elsewhere in the power agreement. It is obvious that by its absence the value of the permit during the latter years of its life, is materially impaired. Power contracts are frequently, in fact generally, executed for periods of not less than five years and frequently for ten or even twenty years.

The contract agreement should include a clause guaranteeing for a period not less than five years subsequent to its termination, the fulfillment of contracts between the permittee and customers existing at that time.

The Permit Revocable

Under the law as it now stands the Forest Service can grant to an individual or corporation seeking to develop water power from Forest Reserves only a permit revocable by the Secretary of Agriculture in his discretion. The so-called "Second right-of-way" act is entitled "An Act relating to rights-of-way through certain park reserves and other public lands," and bestows authority in this matter upon the Secretary of the Interior. A later law, approved February 15, 1901, transferred to the Secretary of Agriculture responsibility for the execution of all laws relative to national forests.

No argument is necessary to demonstrate that a permit revocable in the discretion of the head of a department is not an adequate basis for financing an enterprise requiring investment of capital. This vital defect of the existing law to-day stands squarely in the path of legitimate and praiseworthy enterprise seeking to develop and utilize our many water powers from forest reserves now wasted. Every proper influence should be brought to bear by those interested in the true conservation of our natural resources to secure a modification of the law removing this otherwise insuperable barrier.

An Alternative Plan

The man who criticises adversely a plan which has been elaborated by others is not necessarily under obligation to suggest

an alternative and, moreover in the judgment of the author, any plan which imposes a tax upon water power or fuel is at best of doubtful wisdom. Assuming, however, that upon careful consideration the American people should decide definitely and finally to impose a tax upon natural resources of the public domain, to be used in conserving and developing those resources, it is perhaps not improper to suggest the outlines of a plan which from the standpoint of public policy appears preferable to that now in force. The essential features of the plan which he would suggest are the following:

(1) A tax imposed on all sources of power found upon public lands—a royalty on coal mined and a rental upon water power. The charge for water power to be based not upon an indefinite and disputed relation of forest covering and commercial value of the power, but upon the fact that the Government needs revenue to develop and conserve our natural resources, owns the power, and, as owner, possesses an unquestionable right to impose a charge for its use. The Federal Government is now selling coal lands on the public domain at prices which, on the average, approximate one-tenth of one cent per ton of the coal which it is estimated the property can commercially yield. If the coal be used to produce power under average conditions this tax is substantially equivalent to 0.5 cent per 1000 kw-hr. as against an average rental of 20.86 cents per 1000 kw-hr now imposed in the case of water power. The theory of conservation unquestionably points to an increase in the price fixed for coal lands or a decrease in water power rental, or both. By adjusting the charges for coal and water power to approximate equality, as measured by their respective ability to produce power, the tendency of the present method to stimulate the use of coal for power purposes as against the use of water power—a tendency which, as the author has stated, is in direct contravention of the fundamental idea of conservation—will be avoided and the aggregate revenue ultimately available to the Federal Government for the purpose contemplated will be enormously increased.

The general features of the present contract agreement enforced by the Forest Service as regards fifty-year limit of the period of appropriation should be preserved. The other restrictions now imposed should also be retained except that certain clauses should be modified to meet the practical objections which have been pointed out, in so far as mature consideration may determine the validity of those objections.

The proceeds of royalties upon the sale of coal land and forest products and rentals of water powers to be used to conserve our national resources by development under broad and systematic plans—to conserve forests, build dams, improve navigation and irrigate the arid lands.

(2) The charge imposed upon water powers to be based upon the amount of water appropriated and the effective head resulting from the topography of the Government lands concerned.

Under the present plan, it is necessary to measure the water used in order to fix the third deduction from the charge based upon output. The difficulty of measuring water, therefore, must be met and it is as easy to fix the second-feet appropriated as to fix the deduction allowed for artificial storage by a permittee.

Under this plan it would be to the interest of the permittee to install a plant of high efficiency and not a plant of low efficiency as the present method of charging suggests.

An important practical point in this connection is the fact that the estimate of competent Government engineers, discussed with and agreed to by the permittee would constitute a safer basis for the investor who may undertake to finance the enterprise than he now has in the data submitted for his consideration by the promoter.

(3) There is a third suggestion which perhaps may be worthy of consideration in view of the fact that conditions as regards cost of development and characteristics of the market for power differ so widely in various parts of the country. That suggestion is that the Government engineers of the departments or bureaus concerned prepare comprehensive preliminary plans for the development of water powers of a given watershed and that these water powers collectively or severally be leased to the highest bidder, the Government, of course, reserving the right to reject all bids.

A paper presented before the Los Angeles Section of the American Institute of Electrical Engineers, March 22, 1910.

ELECTRIC POWER IN THE CONSTRUCTION OF THE LOS ANGELES AQUEDUCT

BY E. F. SCATTERGOOD

The Los Angeles aqueduct extends from the intake in Owens valley, about 12 miles north of the town of Independence, to the storage reservoirs at the head of the San Fernando valley, about 24 miles distant from the city of Los Angeles, from which point the city water department will take care of the distribution of the water. The length of the aqueduct proper is, therefore, 240 miles.

From the southern end north to the north portal of the Elizabeth lake tunnel, a distance of 35 miles, the work is heavy, being to a considerable extent composed of tunnels, including the Elizabeth lake tunnel, some 27,000 ft. in length, through granite rock. Preliminary estimates showed that in such sections the considerable amount of power required could be furnished much more cheaply, from a central generating plant and distributed by high tension transmission, than by small power generating units, either by steam or distillate engines at various points as required. This section is supplied with power purchased from the Southern California Edison Company, and delivered at one of its substations about four miles west of the aqueduct line and near the center of this section. From the Elizabeth lake tunnel to a point 55 miles further north, the aqueduct follows along the desert in the open, and estimates indicated that the conduit excavation, and concrete work of lining and cover, could be done more cheaply with the use of steam shovels and gas engines than by the erection of a temporary electrical generating and distributing system. From the Pinto hills north to the intake, a distance of 150 miles, there are

alternate sections of the heavy tunnel work and of the lighter conduit work. In the Owens valley there are numerous creeks flowing down the eastern slope of the Sierra Nevada mountains offering excellent opportunities for power in sufficient quantities for construction work on the aqueduct; and estimates showed clearly that power could be developed at these creeks and transmitted along this 150 miles, and delivered to all points requiring power, in large or small amounts, at a very much lower cost than that for which it could be furnished in any other way.

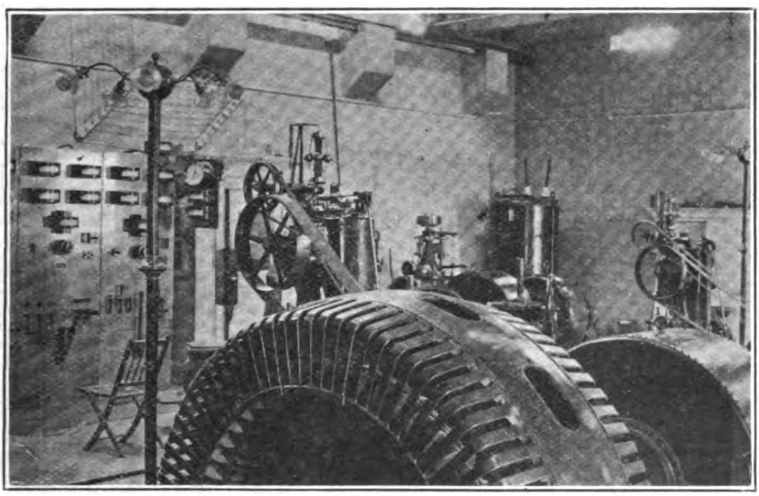
It should be stated for the benefit of those who are not so familiar with the city's project, and who may read this paper, that the power referred to here is for construction purposes only, and should not be confused in any way with the large amount of electric power which may be developed along the line of the aqueduct when it is in operation, and which will total a peak load capacity of 120,000 h.p. delivered at step-down voltage in the city.

Power System

For the purpose of supplying power along the section of the aqueduct from the intake to the Pinto hills, hydroelectric plants were installed on Division and Cottonwood creeks. The Division creek plant is about three miles south from the aqueduct intake, and has a rated capacity of 600 kw. The works at the point of diversion at the creek cost $1,214. The penstock starting from this point, and extending down the slope 10,500 ft., consists of 6,291 ft. of 18-in. riveted pipe and 4,209 ft. of 15-in. lap-welded pipe, and cost, in place, $28,102. The effective head obtained is approximately 1,200 ft. The power house equipment consists of one tangential wheel direct connected to a 2200-volt, three-phase, 600-rev. per min. generator and a bank of transformers, stepping the voltage up to 33,000, each of which has a continuous overload capacity of 25 per cent above the 600-kw. rating. The power house is built of concrete in a substantial manner. This is also true of the second one to be described, as these plants are intended to become a part of the permanent aqueduct power system. The cost of the power house and equipment, including three cottages, etc., is $21,100, making a total cost of approximately $84.50 per kw., or $63 per h.p. rated capacity at the switchboard.

The Cottonwood power house is approximately 40 miles south from the Division creek plant. Its equipment consists of two tangential wheels, operated under 1,200 ft. effective head,

each direct connected to a 750-kw. three-phase, 2200-volt, 600-rev. per min., generator, each of which in turn is connected to the 33,000-volt line through a separate bank of transformers. The works at the diversion point cost $3,964. The canyon for a distance of 3,750 ft. is so precipitous as to make a conduit or tunnel impracticable within reasonable cost, therefore, a 24-in., No. 12 gauge, riveted pipe was buried along the side of the canyon, at a cost of $9,352. From this point to the forebay, a distance of 7,042 ft., a covered concrete conduit, 30 in. by 20 in. inside section, was constructed on the mountain side at a cost of $11,228. The penstock, with 523 ft. of 24-in. pipe and 4,009

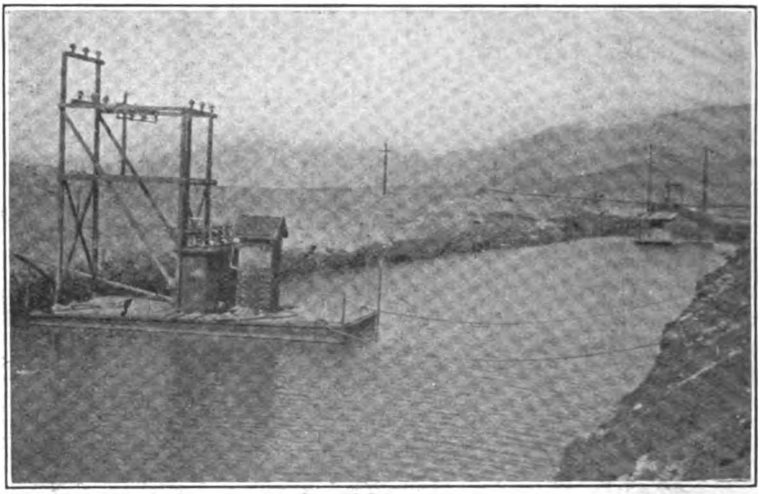


Cottonwood power house—two 750-kw. generators—power all utilized for construction work

ft. of 22-in. pipe, or a total of 4,532 ft., cost $29,820. The power house and camp complete cost $49,638, making a total of $69.40 per kw., or $51.75 per h.p. of rated capacity at the switchboard, the plant having 25 per cent overload capacity.

The transmission line is 151 miles long, and is made up of three No. 4 bare copper wires; two-part seven-inch porcelain insulators with iron thimbles, pins and bases; one wire on a 15-in. crossarm at the top of a 30-ft. pole, and two on a 6-ft. crossarm below, and poles spaced 180 ft. apart. The average cost of this line is $862.50 per mile. About one-fifth of this line is through rough mountainous country, and the wagon haul for

the entire line an average of 12 to 15 miles. This line has since been extended from its southern end to the aqueduct cement plant, a distance of 17 miles, with No. 2 copper, at a cost of $1,050 per mile. The object of this extension is to deliver surplus power to the cement plant, with the advantage of supplementing the steam plant, thus saving fuel oil and making the entire system more flexible and reliable by running in parallel with two 750-kw. steam turbines at that point. Had the cement plant been contemplated originally, more copper might have been used along the whole line, and more generating capacity installed to advantage. As an interesting illustration of the



Floating transformer station used in connection with suction dredge; Owens Valley

value of synchronous condensers in connection with transmission of electric power, it may be stated that while delivering a distributed load of 1000 kw. between the intake and the Pinto hills, 400 to 420 kw. could be delivered at the cement plant, 125 miles from Cottonwood at 30,000 volts with 35,000 volts at Cottonwood when not in parallel with the steam turbines; and that 800 kw. can be delivered at the cement plant when running in parallel, by strengthening the field of the turbo-generators, with the same voltage drop and the same distributed load along the line.

There are about 74 step-down transformers connected to this line in banks of two or three; most of these transformers are of

40 kw. capacity, the remainder are either 20-kw. or 80-kw. The greater number are of the out-door type, which have given excellent satisfaction, and are very much liked by the men in charge of work, because of the decreased expense and time of setting them up. Most of them have been shipped from the factory with the oil in them, as they are in boiler iron cases, made suitable for moving with the oil in place, thus avoiding the necessity for drying out of transformers at isolated places. The protection of this high-tension line against lightning and surge voltages is a combination of low-equivalent arresters at the Cottonwood power house and three sets of horn-gap arresters at other important places. The transformer stations are protected by air-insulated choke coils and fused horn-gap switches. The comparatively small insulators for the voltage used, while they have given no trouble whatever, do undoubtedly serve to give additional protection to apparatus along the line by affording relief from any excessive potential. No apparatus has been lost from lightning or surges during the eighteen months of its operation.

By including interest, placing a proper depreciation on the permanent power plant, and assuming a low value of return from the copper on the temporary line, and on the transformers constituting the substations, (the system to be in use but four years), it was estimated that the cost per kilowatt hour delivered at a step-down voltage, in large and small quantities as desired, would be approximately 1.15 cents. The indications are that this estimate will prove to have been conservative.

Uses of Electric Power

Stating as briefly as possible the uses to which this power is put; there are in Owens valley about 20 miles of the aqueduct which can conveniently be built with dredges. Four electric shovels are in use for conduit excavation in the open country. One mill for regrinding tufa with the cement is located at Haiwee, 22 miles south of Cottonwood. Electric power is used at Haiwee, also for sluicing and other work connected with the building of the earthen dam. There are approximately 18 miles of rock tunnels and three miles of earth tunnels provided for by this power system. The typical tunnel equipment consists of one air compressor, driven by a 100-h.p., 440-volt, three-phase induction motor; one 80-kw. motor-generator set, providing 250-volt direct current for electric locomotives; lighting and

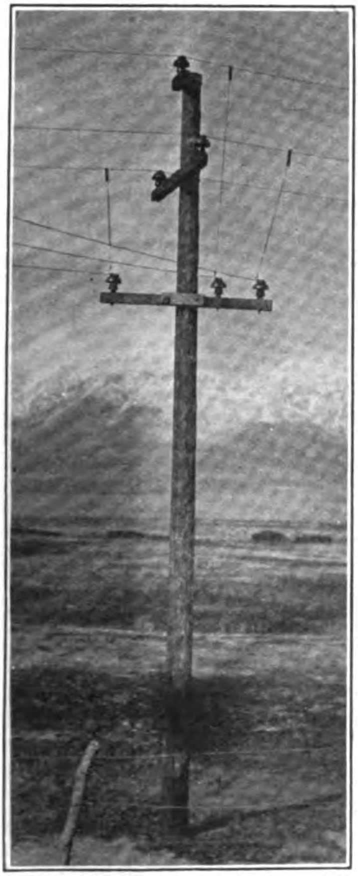
other work inside the tunnels; other power for blowers, machine shop, hoists, pumping, etc., as the case may be, and for lighting camp. In case electric locomotives are not used, as in shorter tunnels, alternating current at 110 volts is used for lighting in the tunnels also.

Dredges. There are two suction dredges in operation in Owens valley, each equipped with a 12-inch centrifugal pump, driven by a 100-h.p., 440-volt induction motor; one 40-h.p. motor to run the cutter, one 40-h.p. motor to run the jetting pump for breaking down the bank over the cutter, and one 20-h.p. motor for operating various hoists. There is also one dipper dredge of one and one-half yards capacity of the friction type, driven

Dipper dredge in Owens Valley

by one 100-h.p. induction motor. The step-down transformers in each case are mounted on a float, with the rack overhead supporting the choke coils and switch on which the taps from the transmission line land. The line being close by requires but one short span, and a crossarm is placed on the round cedar pole by clamping it with two bolts and a short piece on the back, as shown in the illustration, then pushing up at a safe distance from the lower arm. Connection is made with the line through long spiral springs of tempered brass and a brass clip at the end. These are put in place by means of a long pole from an insulating stand, or by climbing a short distance up the power poles, with the line switches at the transformers open, and the transmission line hot, which necessity requires, and which cannot result in

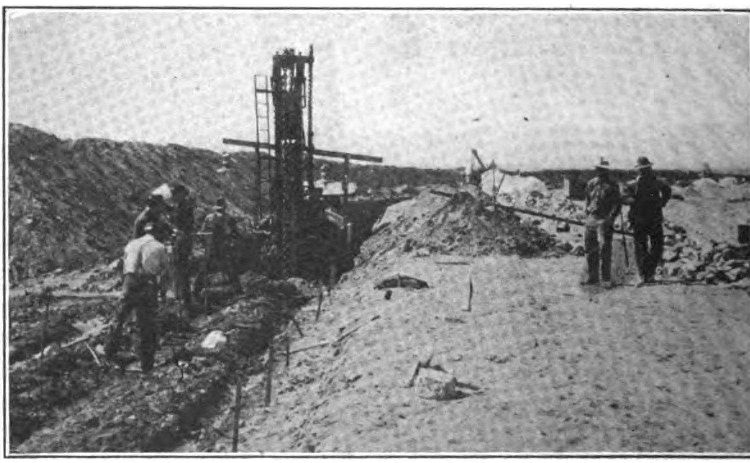
personal harm when done by an experienced lineman, as is the case. The connection from the transformer float to the dredge is made by means of a three-conductor submarine armored cable. The cable is stored on a reel on a second float attached behind the dredge, with flexible connections to the dredge, so that the cable is automatically paid out, and when all out the flexible connections are detached and the cable wound up, then the reel float and the transformer float are towed up to the dredge together. This method has proved very satisfactory in avoiding abuse to the cable and in saving time and expense in moving.



Method of connecting portable substation to 33,000-volt transmission line

Electric Shovels. Electric shovels with three-quarter yard buckets, and 25-ft. booms, used for conduit excavation, are of the friction type, driven by one 75-h.p., 2200-volt induction motor. The step-down transformers are mounted permanently on sleds or trucks, with the racks supporting the choke coils and switches permanently fixed overhead, and with two 10-kw., 2200- to 440-volt transformers attached, supplying power for concrete mixers operated in connection with each shovel. The cable used is three conductor No. 10 with rubber insulation, rounded out with jute, taped with weather-proof braid and half round steel armor over all. This connects between the transformers and the shovel and between the temporary 440-volt line on the power poles (about 1000 ft. back from the transformers) and the mixers, and is giving excellent satisfaction. The considerable advantage experienced with the use of out-door type transformers in connection with dredges and shovels is very evident.

Electric Locomotives. Twelve three-ton electric locomotives rated at 1200 lb. draw-bar pull at six miles per hr. are in use in this section of the aqueduct. At each end of the Elizabeth tunnel, which is not supplied from this power system, there is one locomotive of this size and one six-ton locomotive. In that tunnel, which is approximately 90 sq. ft. in section when lined, the larger locomotive is preferred, making it possible to pull out 14 to 16 cars of muck at one time. The three-ton locomotives are of good size for the tunnels in the section under consideration, which are approximately 70 sq. ft. in finished section, and range from 2000 to 10,000 ft. in length where locomotives are used. The use of electric locomotives in these tunnels results

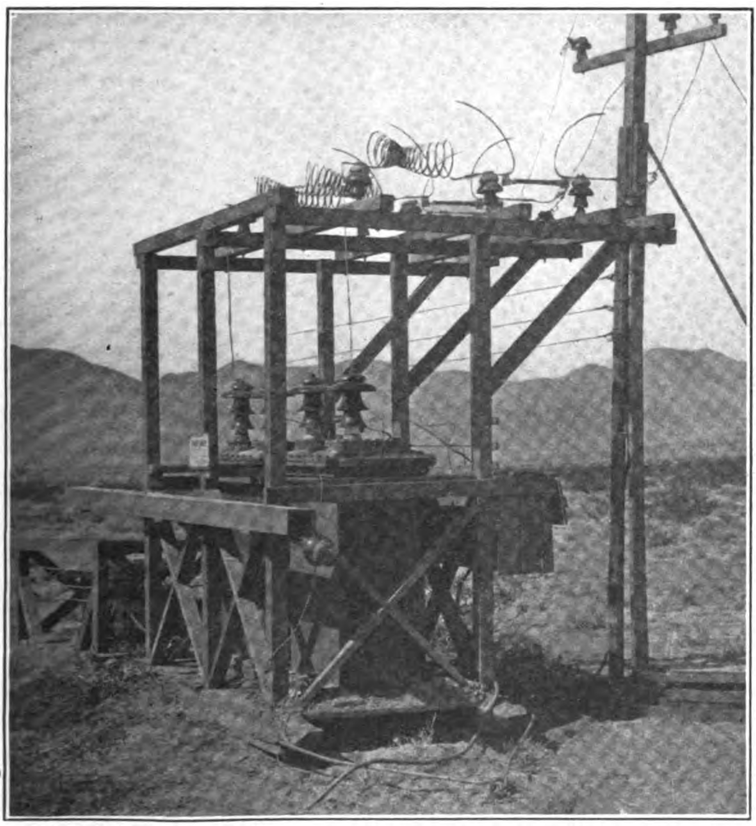


Electric shovel on open conduit; Mojave Valley

in a reduction in cost of excavation and placing the concrete lining, which is a considerable percentage of their total cost. The actual cost of removing muck and delivering concrete is considerably less than it would be if done in other ways, especially by mules; but the greater reduction in cost is due to the practical condition of being able to get the muck away for the convenience and economic working of the miners in excavation, and allowing the placing of rock crushers and concrete mixers at a conveneint point outside of the tunnel for concrete work. Concreting is being done successfully and with perfect satisfaction to the engineers at a distance of 10,000 feet in one instance. This use of these machines makes it possible not only to reduce

the cost where speed is not a consideration, but to very materially increase the speed, if desired.

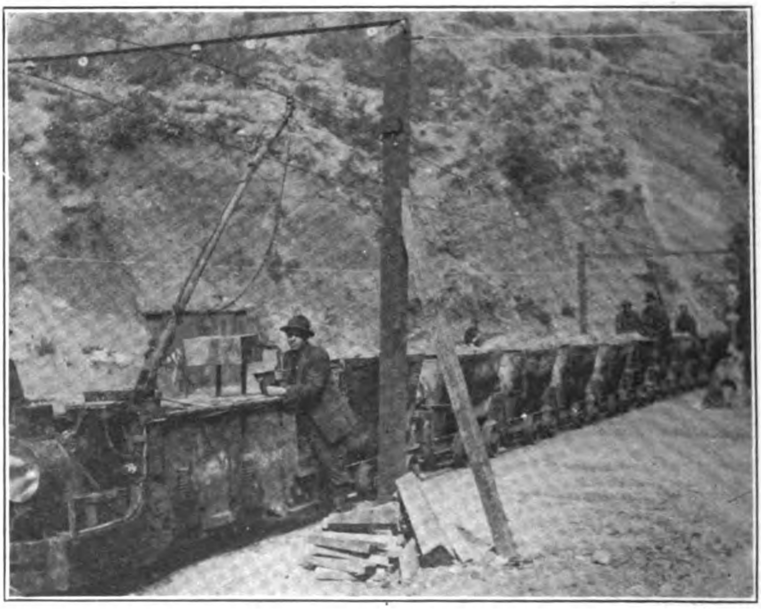
Small Isolated Power. Experience with distillate engines in connection with concrete mixers and other small power has led the men in the field to plead for electric power; for example, several steam shovels are in use in this section for conduit



33,000-volt portable substation—outdoor type transformers

excavation, and it was thought at first that the expense of stepping down the voltage, moving transformers, etc., for supplying two or three motors of 7½ to 10 h.p. each would not be justifiable but the division engineers now insist that the cost of maintaining and operating distillate engines under the conditions experienced along such work is in itself greater than the cost of supplying the electric power, including the charge made against

them for the energy, as well as the equipment, beyond the transformers; and they further state that the interruptions which they have experienced in concrete work with distillate engines behind a single steam shovel, as compared with what they have experienced in concrete work with electric power behind an electric shovel, has cost them anywhere from $20 to $40 a day after the engines had been in use a few months and began to develop troubles under those conditions of operation; in other words, the saving is due to the consideration of reliability aside



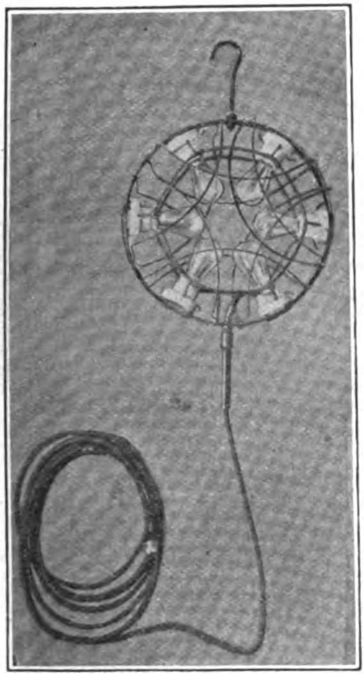
Electric mine locomotive; Elizabeth Lake tunnel

from actual cost of supplying power to the mixers. The cost for tunnel work is considerably reduced and the speed increased by electric lighting. The illustration herewith shows a type of home made cluster, which is giving excellent results at the headings.

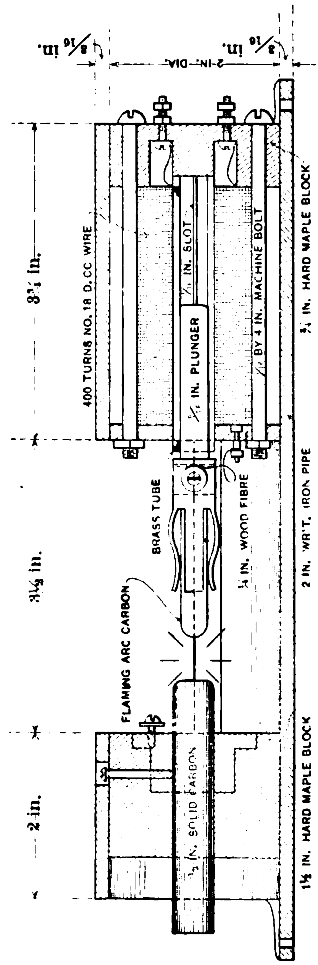
PROTECTION AGAINST GASES

One of the long tunnels in another section runs through an oil district, and at times has developed considerable explosive gases. In order to protect the men against this danger, electric sparking devices have been installed, designed as shown in the illustra-

tion. They may be operated either by alternating or direct current. They are operated by direct current in this case by means of a switch outside of the tunnel, and as may be seen, are absolutely positive in their action and cannot fail if properly



Lamp cluster used in tunnels and designed to reduce lamp breakage from blasting, etc., to a minimum.



Sparking device for exploding gas in tunnel

trimmed when the miners leave the tunnel. They have exploded gases several times, and in the form shown are usually found intact after the explosion; several of them being in use gives opportunity for further trials before entering the tunnel.

Amount of Power Required

A good idea of the amount of power necessary to operate the equipment may be obtained by studying the following tabulation, which gives the total rated motor capacity, approximately 3470 h.p., of the various equipment attached to this system, and the total electrical horse power, approximately 2000 h.p., required at the switch board of the two power plants combined for supplying this system independent of the cement plant. The energy necessary for lighting machine shops and other small requirements is not tabulated, but is included in the power at the switchboard. In many instances power is used 24 hours each day, but in other cases during 16 or 8 hours per day; on an average about 16 hours per day. The amount stated as being required at the switchboard is taken from the heavy load periods during the day; in other words, the average peak load for that work. The average load during the 24 hours would be about 60 per cent of this.

Motor Installation Intake to Pinto Hills

2 suction dredges	400 h.p.
1 dipper dredge, 1½-yard dipper	100 "
4 electric shovels, ¾-yard dippers	300 "
Tufa regrinding mill	200 "
Haiwee dam, hydraulic work	100 "
8 air compressors, 500 cu. ft. each	800 "
8 motor generators, 80 kw. each	1000 "
7 rock crushers, 10 and 20 tons per hour each	140 "
28 concrete mixers, 6 and 10 cu. ft. per batch	280 "
7 blowers, 1350 cu. ft. per minute each	70 "
3 hoists	60 "
2 pumps	20 "
Total rated capacity of motors	3470 "

The average power used at each end of the Elizabeth tunnel, already described, is 88 kw. during the 24 hours, divided, as follows: 5½ kw. for lighting outside the tunnel; 35½ kw. for operating the motor-generator which supplies power for ventilation, electric locomotives, lighting the tunnel and a small amount of pumping from the tunnel; and 47 kw. for compressed air for drilling, machine shop, camp water supply, etc. The average peak is about double the average load.

Telephone System

The telephone system is considered not only one of the most profitable adjuncts to the aqueduct construction, but one which

is essential to its economic construction at reasonable speed. It consists of approximately 260 miles of main line from the Los Angeles offices to the intake, built of two No. 10 copper wires strung on redwood poles, at a cost of $188 per mile. This line is divided in three sections by two exchanges, which more than doubles its efficiency. In addition to this there are local telephone systems in each of the various divisions along the work; some of these have as high as 26 telephones. Each local system may be temporarily connected with the main line by a switch in the division engineer's office, there being but one main line telephone on each division. As the telephone system is to be used by all classes of men, very few of them familiar with electrical work, it was though undesirable, if not wholly impossible, to operate it successfully with the line on the power poles. Estimates showed that by making the poles on the transmission line five feet shorter, the telephone line could be placed on separate redwood poles at an equal or slightly less cost, and this has been done. The telephone lines are in every case placed underground at crossings with high-tension electric lines.

A paper presented at the Chicago Section of the American Institute of Electrical Engineers, Chicago, Ill., March 23, 1910.

DIVERSITY FACTOR

BY H. B. GEAR

In the distribution of electricity for lighting and power purposes over a large city, the maximum demand of the day upon the distributing system varies from day to day during the week, and from month to month during the year. The varying length of the day due to changing seasons, the habits of the population served, and the character of the district, whether residence, mercantile or manufacturing, combine to produce this situation.

In residence districts, for instance, the use of light is such that the maximum demand comes at about 7:00 p.m. in winter and at 8:30 p.m. in mid-summer, as shown in the load curves in Fig. 1. In outlying business districts in the large cities and in the central business districts of the smaller cities, the maximum demand comes from 5:30 to 6:00 p.m. in winter or at 8:30 p.m. in summer. It is usually heavier Saturday than other nights of the week. In the central business districts of cities like Chicago the maximum demand comes from 5:00 to 5:30 p.m. in winter, and at various other hours in summer. Here the Saturday load is less than that of other days because of the early closing of offices and shops that day. This is also true of manufacturing districts where the load is chiefly power. In a purely manufacturing district the maximum load occurs at about 10:00 a.m., the afternoon load being from 15 to 20 per cent less than the maximum of the morning. The load curve in Fig. 2 is that of a power circuit which carries some lighting and so has a 5:00 p.m. maximum.

In the larger cities the conditions vary in all of these classes of service more or less with the character of the population.

The habits of the people in the foreign populated wards are different from those bordering on the boulevards, and the requirements of dwellers in apartments are different from those living in houses. In the outlying districts of Chicago, stores are closed Wednesday and Friday evenings, while in downtown districts very few stores are open evenings at all and the use of electricity is limited largely to show window and display lighting. During the summer the loss of demand in residence districts is partially made up by the requirements of the pleasure parks The combined curve for these various classes of service is shown in Fig. 3.

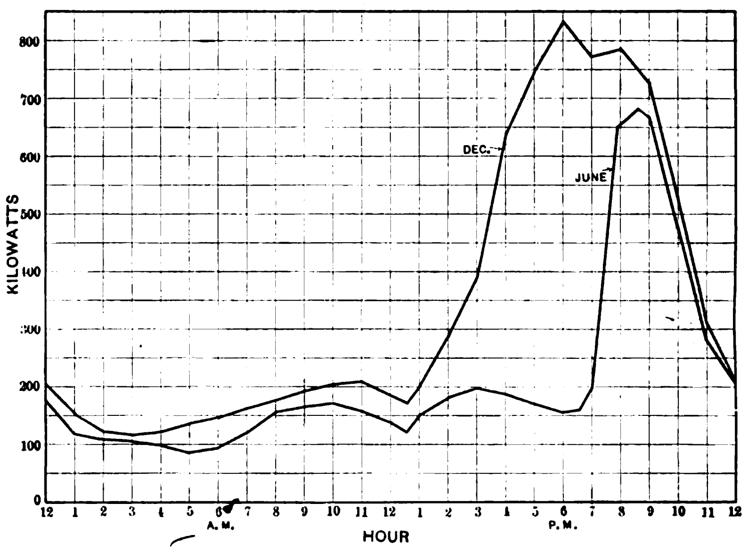


FIG. 1

The combined effect of all these influences is to produce a smaller maximum demand at the generating station than elsewhere in the system. That is, the sum of the maximum demands of the transformers and distributing mains is greater than that of the feeder. The sum of the feeder maxima is greater than that of the substation, and the sum of the substation maxima is greater than that of the generating station.

The ratio of the sum of the maxima of the subdivisions of the distributing system to its actual maximum demand as observed at the point of supply is called the *diversity factor*. Thus, if the sum of the individual maximum loads on the ten feeders

of a substation is 1200 kw. and the co-incident maximum of the feeders is 1000 kw., the diversity factor is $\frac{1200}{1000}$ or 1.20.

The study of diversity factors is of great importance from a commercial point of view as well as being an interesting engineering problem. The investment required by the central station company in the various parts of its operating system for each kilowatt of maximum demand, determines the fixed charges which must be considered in determining costs and in making an equitable system of rates.

The existence of a diversity factor between the demands of a

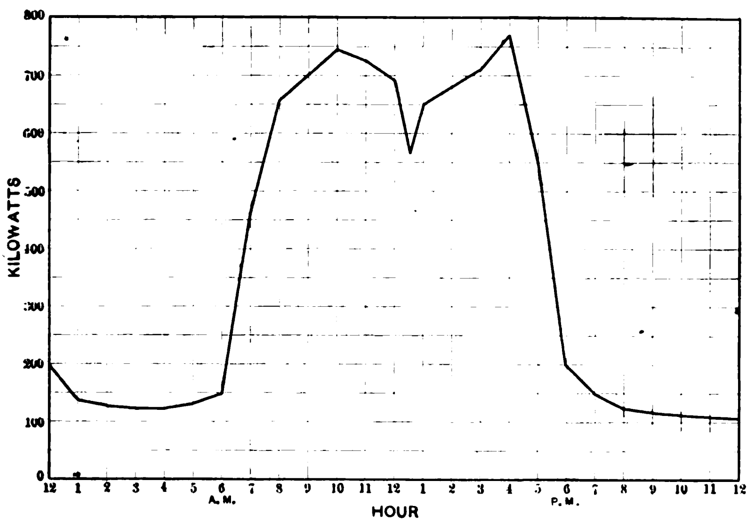


Fig. 2

large number of consumers permits the central station company to supply their demands with a much smaller investment in generating capacity and at a lower cost of production than would be possible if these consumers were operating individual generating plants. This difference must be sufficient to enable the central station to add the financial burden of a distributing system and yet have a margin upon which to sell its product economically to its consumers. The effect of the diversity factor is therefore a subject of interest to both producer and consumer of electricity.

The larger the system the greater the diversity factor and

our study will cover an alternating current system supplied by substations, feeders, mains, transformers, etc., as shown in Fig. 4. An alternating current system has been selected for analysis as it is somewhat easier to observe than a direct current low tension system because of the presence of transformers whose load may be measured. The loads on the distributing mains of a low tension feeder are not so easily measured, and observations therefore cannot be readily made.

The consumer being the originator of the demand for electricity, the development of the diversity factor logically proceeds in the reverse direction from the flow of energy.

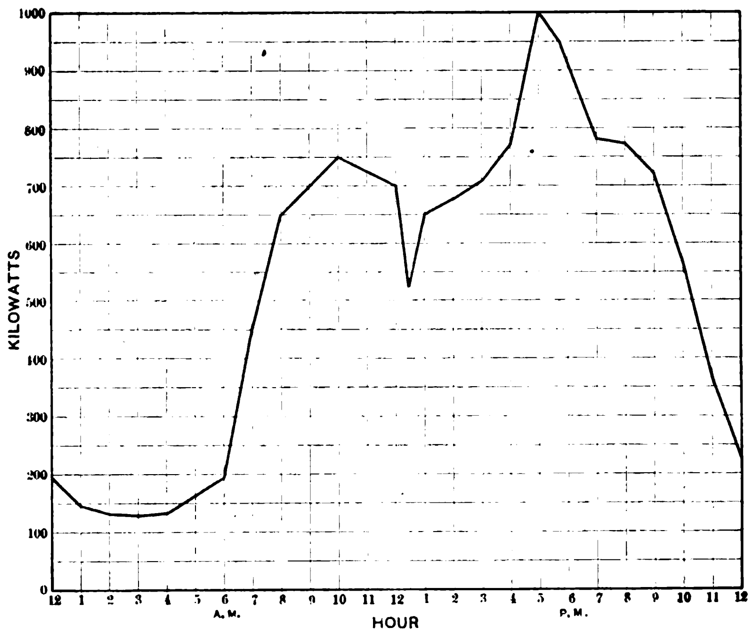


FIG. 3

Observations made in residence districts supplied by overhead lines indicate that the sum of the maximum demands of individual consumers is from two and one-half to three times the co-incident maximum demand on the transformer, the ratio being lower where there are less than ten consumers on a transformer and higher where there are more than thirty.

In commercial districts with numerous small stores supplied by overhead lines, as illustrated in Fig. 5, the co-incident demand is much higher in proportion to the consumer's demands.

The ratio of the sum of consumers maxima to the co-incident demand in this class of lighting is found to be from 1.5 to 1.7, it being lower where there is considerable display of lighting, show-windows, etc., and higher where the shops are of such a character that not all the lighting is needed continuously.

In the block of commercial lighting shown in Fig. 5 there are fifty-five customers, twenty-six services and 1200 lights connected. The measured demand on the transformer at 7:00 p.m.

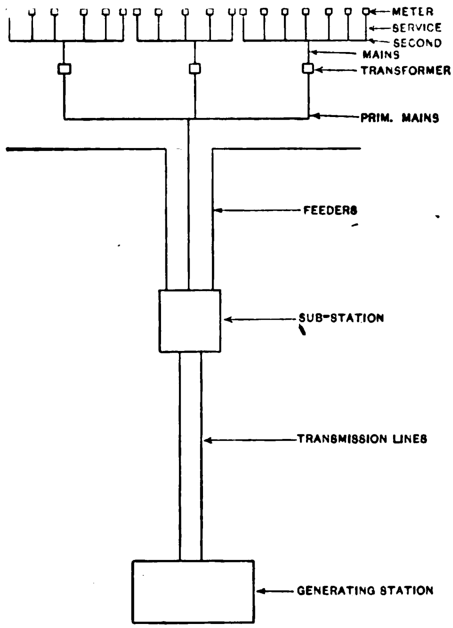


FIG. 4

Saturday is 34 kw. while the sum of the readings of the demand meters is 55 kw. The diversity factor is therefore $\frac{55}{34} = 1.6$. The sum of the demand meter readings is 55/60 of the connected load.

In a densely populated residence block in Chicago the connected load is 2100 50-watt lamps or 105 kw. The consumers' maximum demands aggregate about 63 kw. and the co-incident maximum, as measured at the transformer, is 18 kw. There are

over 175 consumers connected to the transformer. In this case the diversity factor is $\frac{63}{18} = 3.5$, and the consumers' demands are 63/105 of the connected load.

This probably represents as dense a condition as would be found anywhere in a residence district. It is due in this case to the fact that the block supplied by this transformer consists entirely of three-story apartment buildings, in which about 90 per cent of the tenants are using electric service.

Power consumers are not often grouped so that any considerable number can be supplied from one transformer installation. They must be kept separate from lighting customers and therefore usually require a separate set of transformers for each con-

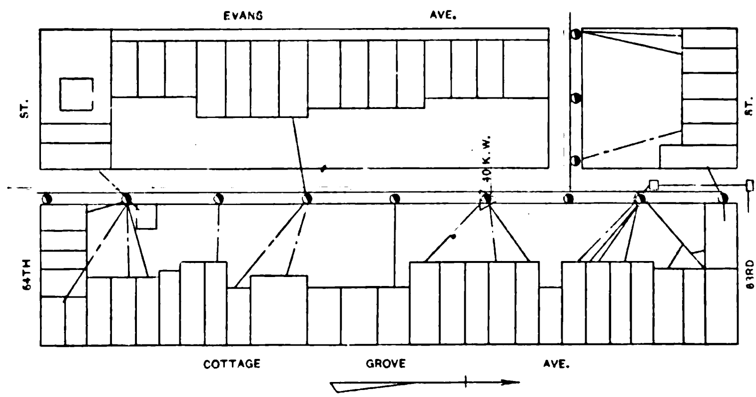


FIG. 5

sumer where the load is 2 h.p. or more. In large installations advantage is taken of the diversity between meters to reduce the transformer capacity installed. This cannot be done with small consumers except in the occasional situations where several power consumers are located within a radius of about 500 feet.

The diversity factor between meter and transformer on power customers is therefore very small and probably does not average over 1.1 for all power installations.

Advancing toward the substation, the next point at which diversity may be conveniently observed, is at the feeder switchboard. There is a considerable diversity factor between the sums of the transformer maxima and the maximum feeder load.

The factor varies with the character of the territory served and with the density of the load. In scattered residence territory where there are many one, two and three-kw. transformers, and few larger than 15 kw., the ratio of maximum feeder load to total transformer capacity is from 45 to 50 per cent. In territory where transformer units vary from 5 to 30 kw., or larger, the ratio is 55 to 60 per cent. In commercial districts with transformers from 5 to 50 kw., the ratio is from 75 to 85 per cent or higher.

Assuming that each transformer carries its rated load at some time during the year, the diversity factor for a feeder in scattered territory is from 2 to 2.2. In denser territory the factor is 1.6 to 1.8 while in commercial districts it is 1.2 to 1.3.

On circuits carrying a scattered power load in units of 5 to 100 h.p., the ratio of maximum load to transformer capacity is from 45 to 50 per cent which makes a diversity factor of 2 to 2.2. Where a few large power customers ranging from 100 to 500 h.p. or more are on a separate feeder, the ratio is from 75 to 85 per cent, making a diversity factor of 1.2 to 1.3. These ratios shift somewhat in a growing system, the tendency being to reduce the diversity factor as the territory becomes more densely built up. They are also modified somewhat by the losses on feeders and mains which may be as much as 15 to 20 per cent.

In the substation, there is a diversity factor due to the difference in the character of the load carried by the different feeders. The maxima on the power feeders occur during the daylight hours while the maxima on lighting feeders vary from 5:30 p.m. in commercial lighting to 7:00 p.m. in residence lighting.

With three-phase distribution, there is a diversity factor between phases where the lighting is carried single-phase. The net result is that in a substation with ten or more feeders the diversity factor averages about 1.15. In the substation supplying power feeders and general lighting it is likely to be as high as 1.2 while in a residence district with little power load, it is about 1.1.

Having thus analyzed the diversity between the various elements of the distributing system it is of interest to derive the total diversity factor from substation to consumer for various classes of business. For convenient reference the following table of diversity factors will be useful.

	Residence	Commerical light	Scattered power	Large users
Substation to feeders	1.15	1.15	1.15	1.15
Feeders to transformers	1.8	1.25	2.0	1.25
Transformer to meters	3.0	1.6	1.1	——
Total diversity factor	6.20	2.30	2.53	1.44

From this table it is apparent that the total diversity factor for residence lighting is 6.2, for commercial lighting 2.30, for scattered power 2.53 and for large users of light or power 1.44. The latter figure would apply to consumers requiring from 100 to 500 kw. The combined diversity factor of systems giving all of these kinds of service should range from 2.5 to 3.5 depending upon the relative proportion of each kind served.

These factors may be illustrated by a concrete example:

Assume a residence district, well settled, in which the sum of consumer's demands during the heaviest month of the year is 100 kw. The transformer capacity required to carry the coincident demands of these consumers will be $\frac{100}{3} = 33.3$ kw. The feeder capacity will required be $\frac{33.8}{1.8} = 18.5$ kw. The substation capacity required will be $\frac{18.5}{1.15} = 16.0$ kw.

Similarly, the capacity required for a commercial lighting district in which the sum of the consumer's demands is 100 kw. will be 43.5 kw., for scattered power it is 39.5 kw. and for large light or power consumers, it is 69.5 kw.

This reduction in the amount of capacity required in generating and distributing equipment makes a corresponding reduction in fixed charges which form a large part of the cost of producing electricity. The investment cost is further reduced by the ability to use large generating units which cost less than half as much per kilowatt as the cost of generating machinery in the sizes commonly used for independent plants.

The merging of all these demands has also a pronounced effect on operating costs, in that the load factor of the generating station and distributing systems is very much higher than that of the consumers who take their supply from it. This permits the station to be run at an economical load a large part of the time, thus reducing both labor and fuel cost per unit generated.

The combination of these economies constitutes the central station's justification for existence and it is unnecessary to add that the justification is well nigh complete in these days of steam turbines and 20,000-kw. generating units.

Thus far the point of view has been from the consumer toward the central station. It is important however that the situation be seen from the point of view of the central station toward the consumer, as the diversity factor has a very marked effect upon the investment accounts which must be carefully considered in determining the cost of rendering the different classes of service.

Stated in the reverse manner for each 100 kw. of substation capacity used to supply residence lighting, the central station company must provide 620 kw. of meter capacity, 207 kw. of transformer capacity, and 115 kw. of feeder capacity. In serving large light or power customers it must provide 144 kw. capacity in meters and transformers and 115 kw. in feeder capacity for each 100 kw. of substation capacity.

The diversity factor for small and scattered consumers is higher than these figures and they require more equipment and a larger investment than is required for the consumers in thickly settled districts.

The investment required per kilowatt varies considerably with the type of construction and the geographical situation of points of supply and delivery. It is considerably more for underground lines than for overhead, and no figures can therefore be given which will have great value for other systems than the one to which they apply.

It may, however, be instructive to give some figures to show in a general way how the investment is distributed between various parts of the system under a set of assumed conditions, which are fairly representative.

Assuming the average cost of a meter at $10, line transformers at $7 to $10 per kw., transformer substations and transmission lines at $35 per kw. and generating station capacity at $150 per kw., the investment is divided approximately as shown in the following table.

It is apparent from these figures that as far as that part of the cost of electricity supply which depends upon investment is concerned, small and scattered consumers are the most expensive to serve. This is due chiefly to the high investment in meters and distributing mains. For instance the cost of meters in residence lighting is about 25 per cent of $820 or $205 per kw.

of station demand. This means that if all the consumers were of this class that the company would have as much money invested in meters as in generating plant.

	Scattered power per cent	Scattered residence per cent	Dense residence per cent	Commercial light per cent	Large users per cent
Generating capacity	37.0	18.5	30.0	44.5	60.0
Trans. line and substation	9.0	4.5	7.5	10.5	14.0
Feeders and mains	49.5	52.0	26.0	35.0	23.0
Transformers	4.0	4.0	2.5	3.0	3.0
Meters	0.5	21.0	34.0	7.0	negligible
Total	100.0	100.0	100.0	100.0	100.0
Investment per kw. of annual maximum demand on generating station	$410.00	$820.00	$500.00	$350.00	$250.00

The commercial lighting and power business where the diversity factor is smaller and the size of consumers larger, requires less meter investment and more in generating and substation capacity.

The maintenance cost of a large meter and distributing equipment and the general expense items of meter reading, billing, etc., are correspondingly high for small consumers, so that it is probable that the outlying parts of the distributing system are served at a loss during the earlier stages of development.

The study of diversity factors has not been carried out in as much detail heretofore as is desirable. These deductions are presented as a tentative contribution to a subject which has many angles and must submit to revision as experience and more careful observation may demand.

They should in no wise be considered as the last word on the subject as parts of them have been necessarily drawn from sources that could not be thoroughly verified.

It is believed, however, that as a whole, they are sufficiently near the facts to form the basis of intelligent discussion.

DISCUSSION ON "ELECTRIC DRIVE IN TEXTILE MILLS", CHARLOTTE, N. C., MARCH 30, 1910. (SEE PROCEEDINGS FOR APRIL, 1910.)

(Subject to final revision for the Transactions.)

Mr. Milmow: In reference to the first cost of electric drives, we have taken the figure at $33 per horse power, which includes a great many things ordinarily not required in the electrical equipment of the mills. The $33 includes all the shafting and belting, fire protection, and reservoir, and other things of that kind. A new mill can be equipped, or an old mill converted, as a complete installation, as far as electric motors and wiring are concerned, for about $15 a horse power, maximum, and has been done as low as $12 per horse power. After several years of experience I can highly recommend the use of high voltage motors, and wish to say that we consider that the use of 550-volt motors handicaps a mill at the start and handicaps its future development. It requires more power, and introduces entirely unnecessary losses in the transforming of power, but the 2,200-volt motors, of which we have had a large number in use, have done their work and carried out their service with practically no repairs and with general satisfaction to everybody.

C. F. Scott: Aside from the particular points which are dwelt upon in this paper, I have been interested to note how many of the advantages which are brought out are those which are incidental. Although in this paper the cost of the power is the essential thing set forth, and although it is shown that the cost of electric power is less than that of steam power, yet the great advantage does not lie in the simple cost of the power, but in indirect elements; in the superiority of the motor, in its general convenience, flexibility, and adaptability, and in its constancy of speed. The power can be considered both from the quantity and quality standpoints and it is the quality standpoint which seems to me to be the strong one, and the important one, as is stated in this paper.

An interesting point is brought out in regard to the location and arrangement of the mill—in a steam-driven mill the steam plant must first be designed and the lines of shafting laid out as may be convenient for the engine. The building and arrangement of machinery is secondary to engine, shafting and belting. On the other hand, in the electrically-driven mill, the design can be made, not from the standpoint of power, but from the standpoint of the operations. The power becomes secondary, and the whole arrangement of the mill can be made most economical and most serviceable and efficient, so as to better serve its real purpose of economic production. The mill itself can be installed in any convenient place without reference to waterfalls or convenient proximity of condensing water, and the motor can be put up on the ceiling where it will take no room. Further this paper shows an increase in production by the gain in speed constancy. These indirect things make for better and larger

production through the higher efficiency which can be gotten from the operation of the mill and the labor which is there employed.

In the study of a problem of this kind, we have a most excellent illustration of the advantages attained by taking a broad view of the situation. We find here, as in many other cases, that the indirect advantages in the use of electricity, may be of far greater value than simply the saving in the cost of power.

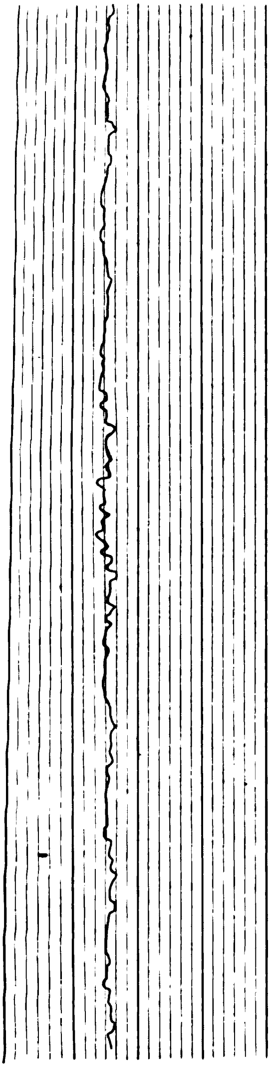
W. S. Lee: If you will refer to the chart on page 439, which represents a curve taken by indicating an engine every ten minutes for a period of one week, you will find a rather interesting condition of affairs. That is one of the best and most economical mills in the whole territory. You will note that on Monday morning the mill began with a very heavy load, something over 2900 h.p., and that this load ran fairly steady during the forenoon, but in the afternoon dropped off considerably. This same condition obtained on Tuesday. I call your special attention to the last few hours on Wednesday. I ask you also to note the last hour on Thursday, and the last hour and a half on Friday. These curves present a graphic picture which shows that the mill is not being operated up to the proper efficiency. The production of the mill was decreased, due to the fact that each department was not kept up to the highest standard of efficiency, as it did not work its full number of hours per day. This shows the importance of keeping a power curve, which will show what the mill is doing. A manager can tell from his power curve whether the mill is being run properly.

I do not know that I can explain this subject of speeds more thoroughly than is done by these curves. Speed means a great deal in output to cotton mills. Cotton mill machinery is built to operate automatically. If a thread or any part breaks it stops the machine automatically and it takes a certain time for the operator to get to this machine and get it started. Furthermore, the momentary variations in speed cause certain pulsations which, when magnified, produce a cadence throughout the mill. These pulsations very often break thread and stop the machine, which normally would not occur if the speed was more uniform.

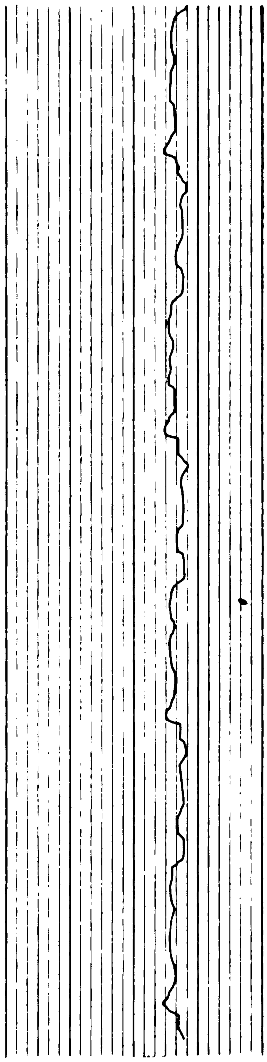
I want to call your attention especially to the charts on page 470. These are from a mill with which we have a contract to furnish power; it is now operated by steam and has a speed variation of 16 per cent. If you will put an ordinary tachometer on the end of the shaft, and take speed for one minute, it will show good speed, but this does not show the variation up and down as shown by this curve on a large scale. The variation from the average speed is eight per cent below and eight per cent above.

Since the charts referred to on page 470 of Mr. Milmow's paper were taken, showing variation of this mill while being driven by steam, the mill has been electrically equipped and is

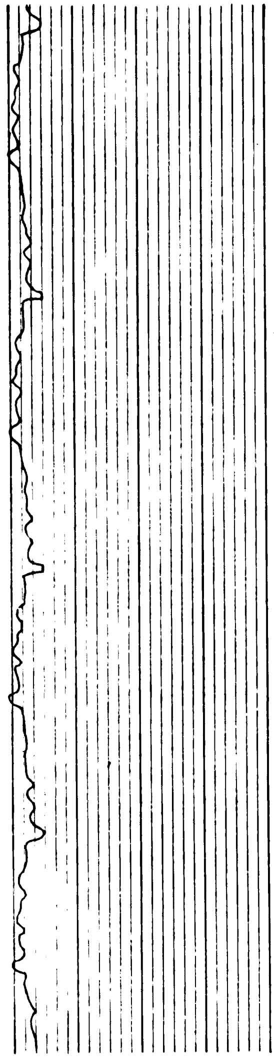
now operating by electric power. Chart No. 1 shows a 60-h.p. motor in this same mill driving cards; chart No. 2 shows a 60-h.p. motor on spinning frames; chart No. 3 shows an 85-h.p.



No. 1



No. 2



No. 3

motor on spinning frames. By observing these charts it will be noted that the extreme variation is from 2 per cent to 3 per cent, and most of the time less.

If you can use a power in the mill that will have only three

per cent speed variation, you immediately move your average speed up six-and-a-half per cent higher than you had it before. If you move the speed up six-and-a-half per cent, we know more goods are made, and we know it takes more power to do it. The results of changing over a lot of these mills have been different in almost all cases. In some cases we have increased the amount of power, in other cases we have decreased it. Where we have increased the power consumption we have increased the production.

There is another matter to which I desire to call your attention, and that is in connection with extensions of the mills. All mills in this part of the country are built with the idea of increasing or extending them. I do not believe there has been one mill built down in this part of the country that its president and manager did not contemplate increasing its capacity. Now, if that is the case, it is impossible to lay out an economical or efficient steam plant that is susceptible to that variation. In the case of the electric drive, the mill manager can put in what he needs for his present purposes, and as the business increases and he extends the mill he can build on to it additional sections.

A. W. Henshaw: I think the curve given on page 473 is particularly interesting, as showing the very rapid increase in the application of electric power to textile mills in this part of the country.

The Census reports for the year 1900 show that the total power used in cotton mills in the United States was approximately 800,000 horse power, which had increased to approximately 1,000,000 horse power in 1905. This is an increase of 28 per cent. Deducting from that figure the power used in the states of North Carolina, South Carolina and Georgia, the amounts are 628,000 h.p. in 1900, and 700,000 h.p. in 1905, which is an increase of eleven per cent; whereas in North Carolina the power used in cotton mills had increased sixty per cent in these five years, and in South Carolina and Georgia one hundred per cent, showing that the great increase in the cotton industry has been recently in these southern states, a very marked condition as compared with the other states of the Union. I am speaking particularly of the total power used in cotton mills, whether supplied electrically or otherwise.

It is interesting to see also what a large percentage of that power is used in this particular section of the country as compared with the power used in all lines of manufacture. In South Carolina there were 156,000 h.p. used in cotton mills in 1905 out of a total of 221,000 h.p.—that is, seventy per cent of the power used in manufacturing in South Carolina was applied in cotton mills. In North Carolina there were 93,000 h.p. used in cotton mills, out of a total of 219,000 h.p., which is 42 per cent.

The amount which is applied by the use of electric motors has increased very rapidly, and is continuing to increase. The State of South Carolina has been far ahead of any of the other states in that respect. In 1905, approximately 19 per cent of

the power used in cotton mills was applied by the electric drive, and in North Carolina only about two per cent. That there has been a very rapid increase since then is shown by the curve to which I have referred.

I believe that when we obtain the results of the census for 1910 we shall see a great increase, and that this particular section of the country will be far ahead of any other in the large amount of power supplied through the electric drive in cotton mills.

D. B. Rushmore: Mr. Milmow's paper is of interest in connection with the statements recently made that this country is passing from the position of an agricultural nation to that of an industrial one. The use of electricity for manufacturing purposes is old, but its rapid extension into all such lines is one of the phenomena of the present time.

In the paper under consideration we have an interesting comparison of the steam plant in a particular mill, and electricity taken from a large system—a comparison which must be made in detail in many different individual cases. In general, it is much more economical for the generation and distribution of electric power to be concentrated in the one large system and for the manufacturing industry to buy such power, rather than to generate it in a small plant of its own.

Mr. Milmow has brought out a large number of interesting points illustrating the advantages of electric drive. Many of these are applicable to other forms of industry, and this will be one of the valuable uses of his paper.

L. T. Robinson: I would inquire if Mr. Milmow will take a moment to explain how the speed curves were taken; that is, what sort of an instrument was employed in taking them, and what the time scale on the curves is? I would also call attention to the value, to all concerned in the industrial application of motors, of just such curves as those, shown on page 439. Perhaps he will carry his investigations further and obtain curves on individual machines. The opportunity is always there to use curve drawing instruments on individual motors to check operating conditions and to know if the motors are being run to their full capacity at all times.

Mr. Milmow: We obtained these curves by means of a tachometer specially constructed by Messrs. Schaeffer & Budenberg, applied to the shaft under test by means of a belt. We checked up all these measurements very closely, and one of our curves, Fig. 6, has been inserted there to show the accuracy of the instrument. We have checked the instrument a number of times to determine its accuracy. The instrument itself is rather expensive and cumbersome, and I do not think it would be feasible to apply it in general to industrial applications.

Mr. Robinson: What is the time scale?

Mr. Milmow: That is given in the paper, and is approximately one-half inch in length of the chart, equals one second. You can see that the wave variations are decidedly instantaneous ones.

Discussion on "Gas Engines in City Railway and Lighting Service", Charlotte, N. C., March 30, 1910. (See Proceedings for April, 1910.)

(Subject to final revision for the Transactions)

H. K. English: I have been greatly interested in Mr. Latta's paper on Gas Engines. The record given of plant performance showing a total shut-down of but two hours and forty-five minutes for the year is indeed an enviable one. Also, I consider the data given on operating costs of particular value, as it bears the stamp of "real life" instead of being an engineering estimate, which at best is often only a "wise guess".

It is to be regretted, however, that the items of interest and depreciation have been omitted. Figures on cost of generating power, with these items omitted, are very misleading, this being particularly true of a gas engine plant where installation costs vary widely and little is known regarding such costs. If Mr. Latta would give some figures on installation costs of the plant under consideration, it would add greatly to the value of the other data given.

I would also like to ask Mr. Latta how often he finds it necessary to shut down his gas generators for cleaning, and how long a generator is out of service during this cleaning process.

F. D. Gatchell: Referring to the paragraph of this paper dealing with the piston rod packing, I would like to state that while it is true that the piston rod packings are removed occasionally to be cleaned and adjusted, this is becoming more and more infrequent owing to a better knowledge of how to adjust and assemble this packing before placing it on the piston rod and also to a much better system of lubrication. When these engines were first placed in operation considerable trouble was experienced by the blowing out and leaking of the packing, and if this condition was allowed to go on for any length of time the garter springs holding the segments in place were soon distorted owing to the high temperature of the gas blowing through. This made the packing segments warp and not fit the rod properly. We have overcome these troubles very effectively, however, first, by careful study of the lubricating conditions, and second, by a different method of applying the garter springs. After a series of experiments with different kinds and quantities of oil, we believe that we have hit upon a combination which effectively fits this practice. This is borne out by the fact that we have several sets of packing on these engines which have been in continuous operation for several months, one set having been in service for over ten months without cleaning. This is very desirable for these engines as there are eight sets of piston rod packing on each engine to be kept up.

The method we have adopted in regard to installation of the garter springs which hold the segments of packing together, is that instead of using the continuous spring all the way around the packing as formerly, to divide the spring into short sections con-

nected together with links of solid wire. Each piece of spring takes care of one segment of packing and the joints are bridged by the solid wire. It can readily be seen that as the packing nearly always begins to blow at the joints between the segments, these solid pieces of wire will not be affected by the heat as readily as the springs, and do not stretch, allowing the packing segments to get out of place. We are confident that this simple method of installing these springs has reduced our packing trouble considerably and from indications in the operation of this packing, as used now, it should run several months without adjusting or cleaning.

Referring to the paragraph on page 490 which states that there is a slight periodic swing between the pointers of the watt meters; it may be of interest to state that since this paper has been written we have discovered that one of the wattmeters was improperly connected and after removing this trouble the so-called periodic swing has been reduced to a marked degree, so that it is hardly perceptible, which would indicate that the fluctuation was principally an instrument trouble rather than one caused by cross currents between the alternators running in parallel.

E. D. Latta, Jr.: If I may be permitted to add a few remarks by way of discussion of my own paper, I should like to call attention to recent experiments made at the University of Illinois on the subject of the occluded gases in coal. These experiments show that when coal is freshly mined a considerable amount of gas exudes from it and simultaneously an absorption of oxygen from the air takes place. The gas escapes rapidly from the coal when first exposed to air, but the rate of escape gradually decreases until at the end of about two months it has practically ceased. Similarly the absorption of oxygen decreases with the time of exposure but to a much less degree, for the experiments indicated that after two years exposure the coal still showed a marked avidity for oxygen, and it is probable that this condition continues indefinitely.

This slow oxidation of coal may account in part for the difference between railroad weights and the weights of coal as fired, for nearly all consumers of coal who carry a large stock on hand, find it necessary to add a certain percentage to the weights of coal as fired in order to balance with the railroad weights.

The gas which escapes from the coal, when freshly mined, consists largely of hydrocarbons in the form of marsh gas, CH_4 which is well known to be the cause of nearly all coal mine disasters. If the analysis of the coal referred to in this paper were made, or samples taken within two months after the coal was mined, it is probable that a subsequent loss of hydrogen in the form of marsh gas occurred, and that the coal as fired did not contain the heat units that the analysis showed. Assuming a possible loss to the coal of 2 per cent of hydrogen subsequent

to the analysis, the total higher heat value of the coal per pound would be 14,220 B.t.u. which is more nearly the commercially accepted value of good bituminous coal. The engine efficiency would then become 17 per cent instead of 15.8 per cent and the loss of heat attributed to the producer would be materially reduced, for instead of obtaining 4.44 per cent of hydrogen from the hydrocarbons in the coal, there would be found only 2.44 per cent or 20.95 lb. of hydrogen from 859 lb. of coal. The balance of 38.22 lb. of hydrogen would therefore have to be supplied by the introduction of 344 lb. of steam, in the disassociation of which there would be 2,370,863 B.t.u. absorbed from the producer, reducing the total heat units lost in the producer to 5,120,704 --2,370,869 = 2,749,841 B.t.u., or 20.7 per cent. This figure would show for the producer about the efficiency that is claimed for it by its manufacturers.

DISCUSSION ON "MODIFICATION IN HERRING'S LAW OF FURNACE ELECTODES," CHARLQTTE, N. C., MARCH 30, 1910. (SEE PROCEEDINGS FOR MARCH, 1910.)

(*Subject to final revision for the Transactions.*)

Carl Hering: In this very able and interesting paper Dr. Kennelly has made a contribution to our useful knowledge on this subject, which is of considerable value to us as engineers, as he demonstrates that certain correction factors in these simple laws of electrode properties, may be neglected in practical work, or if they are to be included then how to allow for them.

This is of special importance because serious doubt was thrown on the usefulness and reliability of these simple laws by criticism from certain academical quarters on the ground that the premises on which they were based did not include an academically rigid consideration of the temperature variations of the physical constants (which by the way would at present be impossible because they are not yet known). None of these academic critics however did or were able to show quantitatively that the alleged error was really large; they condemned the results of this investigation in a wholesale manner, merely because the assumed simplified premises were not academically exact; although I believe none denied that the results were rigidly correct under those assumed premises.

Dr. Kennelly in this paper has therefore come to the rescue of these new laws by showing with the same tools which the academician is so fond of, that the approximation under more exact premises, is very close, thereby assuring the engineer who is designing furnaces that he may feel safe to use the laws as based on the simple conditions, and that he can safely ignore the academic opposition to them.

His paper affords a very good illustration of how the mathematical physicist can perform services of great value to the practical engineer by solving the more intricate mathematical problems and giving the conclusions in simplified and well digested form for direct application to practice. This, in my opinion is putting mathematics to its proper use, namely, as a tool to produce a useful result, as distinguished from a mere form of entertainment of those physicists who are more interested in mathematical intricasies and gymnastics than in useful practical results.

Some of Dr. Kennelly's results confirm in a more positive way the more general deduction made in the original paper, that as the curve representing the losses is very flat at its minimum point, no great error would be committed, as far as this loss is concerned, by any possible and much greater errors in the cross section due to neglecting the minor factors like the temperature corrections, provided only that the results are somewhere near this minimum point; the simpler formulas enable us to get near this point.

One of his conclusions, namely to the effect that the conditions for a minimum electrode loss and those for no flow at the fur-

nace end, are no longer identical (though still approximately so) when the temperature variations are taken into consideration, has since been confirmed by an entirely different method, and therefore appears to be correct even without his simplifying premise of a straight line heat gradient in the electrode by the ingenious use of which he has succeeded in getting sufficiently accurate results in a case in which the rigidly correct solution becomes extremely complicated. Even when the rigid solution is effected on the basis of straight line laws of variation of the resistivities, it is still only an approximation because it is known that these variations do not follow such regular laws; for graphite for instance the resistivity first falls and then rises again hence the variation even reverses; while for carbon we know it could not fall according to a straight line law because such a line would when prolonged, give a zero and even a negative resistivity which of course would be absurd.

At first thought it seemed that there might be a mathematical inconsistency in assuming as he does, that the heat gradient in the electrode during normal operation, is a straight inclined line, when it is known that this line must be horizontal at the hot end in order to produce the condition of no flow at the furnace end, and really is a parabola. But is seems that this approximate assumption is made only in so far as it concerns the values of the temperature coefficients of the resistivities, and no farther. If so, it is not an inconsistency, but merely means a a slight error in the form of a small per cent of an already small per cent, and therefore can safely be neglected. When an assumption of such a nature serves to greatly simplify an otherwise extremely complex mathematical result, (which another investigator abandoned when he found it too complicated to integrate) it affords another good illustration of the skillful use of mathematics as a tool to arrive at results for use in practice.

I take pleasure in strongly endorsing Dr. Kennelly's use of thermal resistivities (instead of conductivities) and thermomotive forces. I have long used these quantities in my regular work, and would like to have used them in my papers, but I feared that it would meet with disfavor among many who seem to prefer to waste time and brain energy using the more orthodox methods than to reduce these personal losses to a minimum by using quicker and more direct, though unorthodox methods and tools.

President Stillwell: The opportunity for utilizing electric furnaces exists only where cheap power is available. In the case of these southern rivers, which have so widely variable flow, the problem of the utilization of the power developed always raises, not only the question of cost of development, but also the possibilities of finding a market for the power. At Niagara, the company which financed the original development was greatly disappointed by the slowness with which the market developed. It took a long time to con-

vince the people who used steam power in Buffalo that electric power could be substituted to advantage. At that time there was naturally very much greater doubt of the continuity and certainty of transmission than there is today. The result was that at Niagara a number of electrochemical industries were actually developed as a result of the fact that power there could be obtained in large quantities at low cost, and today about two-thirds of the power which is produced by the Niagara Falls Power Company is used in electro-chemical processes, very few of which existed when this power was first made available and attention directed to it.

In certain sections of the south, with its great and comparatively undeveloped mineral resources, there are also water powers in excess of present requirements for existing industrial uses, and we have thought that by directing the attention of the southern members of the Institute in these papers to certain important fundamental facts relating to the design of electric furnaces, some impetus might be given towards bringing the metallurgist and the engineer together in this section to the advantage of the community.

I was told recently that the U. S. Steel Company, in the old factory of the Washburn & Moen Company, at Worcester, is using a very large electric furnace for the production of steel, and that notwithstanding the high cost of power at that point, the improved quality of the steel, the almost absolute immunity from those constituents, such as phosphorus and sulphur, which are harmful in steel for most of its uses, justified this comparatively expensive method of refining the metal.

DISCUSSION ON "PROPORTIONING ELECTRODES FOR FURNACES", CHARLOTTE, N. C., MARCH 30, 1910. (SEE PROCEEDINGS FOR MARCH.)

(Subject to final revision for the Transactions.)

A. E. Kennelly: Mr. Hering's paper is of much importance both from the practical and theoretical standpoints. In its practical aspect, it gives the results of a number of experimental observations on the behavior of electrodes under furnace conditions. It expresses the outcome of these results in tables for easy reference. The numerical bases of these tables are two experimentally determined constants for each electrode material,—the "electrode-voltage" e, and the "specific section" s. As pointed out in the paper, the "electrode-voltage" e is $\sqrt{2}$ multiplied by the square root of the ratio of the electric to the thermal resistivity; while the "specific section" is $1/\sqrt{2}$ multiplied by the geometric mean of the electric and thermal resistivities. The term "electrode-*voltage*" can only be regarded as an abbreviation for the unwieldy phrase "*voltage* drop in the electrode per square root of the temperature drop." Similarly, the term "specific *section*" can only be regarded as an abbreviation for the unwieldly phrase—"cross-*section* times square root of temperature-drop, per ampere, per unit length of electrode." It is evident that these two phrases are too cumbersome for practical use; and that brief names are necessary, even at some sacrifice in verbal precision.

The advantage of the method of measuring these fundamental constants described in the paper is that whatever errors or defects may be included in the process, the measurements are made under furnace conditions; so that, for practical purposes, the data so obtained are likely to be more directly applicable than corresponding more rigidly accurate data, secured by physical laboratory methods.

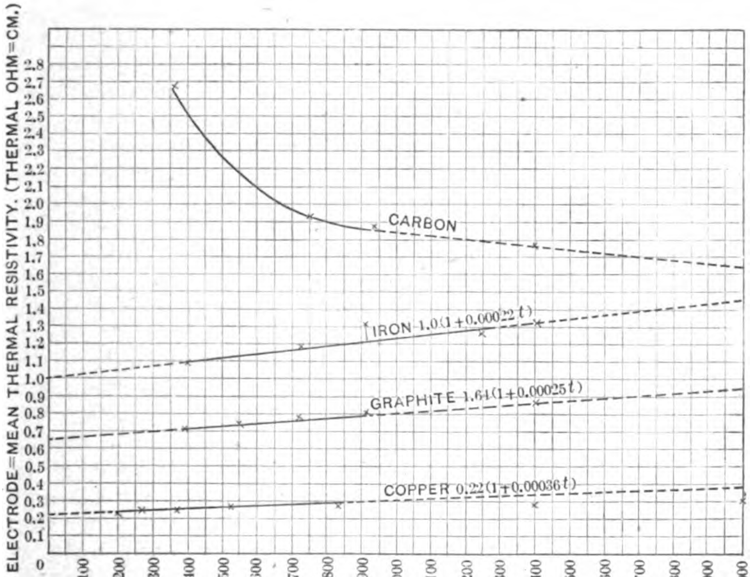
Whatever refinements in the design of uniform electrodes that are uniform in material and cross-section, may be found necessary to meet outstanding sources of discrepancy, such as terminal contact-resistance, lateral escape of heat into furnace walls, disintegration of material, and the like, there can be no doubt that Mr. Hering's paper contains the essential engineering theory of electrode design.

It is a remarkable result of the investigation contained in the paper that copper is superior to iron, graphite, and carbon, as an electrode material, so far as concerns minimizing loss by waste of heat. One would naturally suppose at first thought, that copper would be the worst material of all for this purpose.

In its theoretical aspect, the paper also contains much that is new and valuable. Very little has hitherto been determined concerning the thermal conductivity and resistivity of electrode materials at high temperatures, so that the new data are very welcome. The values obtained are "electrode-means", as that term is defined in the paper on page 301, and are subject

to the limitations involved by that definition. Nevertheless, since it has been doubtful heretofore as to whether the thermal conductivity of electrodes increased or diminished at high temperatures, these pioneer data represent a long step towards enlightenment. If even the sign of the temperature variation has been in doubt, we need not cavil at any lack of numerical precision in the newly determined thermal temperature-coefficients.

In Figs. 1, 2, 3, 4, and 8 of the paper, the electrode-mean thermal conductivities of copper, iron, graphite and carbon are plotted graphically. None of these curves carry any clear graphical self-interpretation. The corresponding numerical values of the electrode-mean thermal conductivity k in what may



be called "thermal mhos per cm." are given in the column fifth from the end in Table I. If we plot the reciprocals of these values, or the electrode-mean thermal-resistivity in "thermal-ohm cm." as ordinates, against the furnace temperature as abscissas, we obtain the graphs of the accompanying illustration. It will be seen that the electrode-mean thermal resistivity of carbon appears to fall with temperature in much the same general manner that its electrical resistivity falls On the other hand iron, graphite, and copper, appear from the results in the paper to follow roughly straight-line laws of increase in thermal resistivity with temperature. Their thermal resistivity follows the course of their electric resistivity in this respect. But whereas in the case of copper, for instance, the electric resistivity at

2,000 deg. cent. appears in the table as approximately nine times the electric resistivity at 0 deg. cent., the electrode-mean thermal resistivity of copper is only about 76 per cent greater at 2000 deg. cent. than at 0 deg. cent. This means probably that the inferred full thermal resistivity is about 150 per cent greater at 2000 deg. cent. than at 0 deg. cent. In other words the temperature-coefficient of increase in thermal resistivity, either in electrode-mean or in full, is apparently much less than the temperature-coefficient of electrical resistivity.

It is to be observed that whereas the electrode-mean electric resistivity of graphite, as given in Fig. 7, slightly falls off with temperature, faintly following carbon, the mean thermal resistivity steadily rises with temperature like iron and copper. This latter result is confirmed by some observations published by Mr. Hansen on page 351 of Vol. XVI of the Trans. Am. Electrochemical Society (1909) for the thermal conductivity of graphite between the limits of 37 deg. cent. and 600 deg. cent.

In the case of iron, we know that the electric resistivity undergoes marked and sudden variations in the neighborhood of the recalescent temperature, a property that is utilized in various forms of "ballast resistance." This disturbance is suggested by the bend in the curve of mean electrical resistivity for iron, on Mr. Hering's Fig. 3, in the neighborhood of 400 deg. cent. A corresponding deviation does not manifest itself in the thermal resistivity results for iron, if we exclude a particular deviation near 900 deg. cent. This is an experimental question that ought to be further investigated. If there is no discontinuity in the thermal resistivity of iron near recalescence, while there is a discontinuity in the electric resistivity, the fact has an important bearing on the theory of electric conduction in metals.

The temperature-coefficients of electrode-mean thermal resistivity in iron, graphite and copper appear from Mr. Hering's table to be respectively about 0.022, 0.025, and 0.036 per cent per degree cent. from and at 0 deg. cent. Consequently we may estimate, as a first approximation, that the full thermal-resistivity temperature-coefficient would be double the above values of 0.044, 0.05 and 0.072 respectively. This is merely equivalent to assuming that, as a first approximation the electrode-mean thermal resistivity is the arithmetical mean of the thermal resistivities at the hot and cold end of the electrode.

If my own paper, accompanying Mr. Hering's paper, had been written with these new constants available, the only alterations in the numerical examples would have been the substitution of $a = -0.0032$ for $a = -0.0072$, the distance coefficient of electric resistivity, and the substitution of $b = 0.016$ for $b = 0.01$, the distance coefficient of thermal resistivity. That is, one of these coefficients would have been reduced, and the other increased. The resulting numerical effect would have been comparatively small; but the general effect would have been to show still less deviation from the deductions of Mr. Hering's original formulas than the numerical examples actually present.

Summing up then the results of Mr. Hering's investigation from the above standpoint, we may say that with the exception of carbon, all of the materials tested showed at least substantially straight-line laws of resistivity, both electric and thermal, all the coefficients being positive, except the electric resistivity coefficient of graphite.

E. F. Northrup: Engineering problems may be classed, roughly, into th se which aim to produce a material result for the first time, as building a Brooklyn bridge, and those which would repeat engineering accomplishments with better economy.

Mr. Hering's problem belongs to the latter class. He sees that there is an important engineering question to answer, which is this: How, with data which can be obtained practically, shall the material of furnace electrodes be selected; and having this, how shall it be proportioned so that, with the furnace temperatures required, the electrodes shall not chill the furnace charge while the power wasted shall be the least possible.

It is not a problem for elegant mathematical exposition, based upon assumptions that thermal and electric coefficients vary as idealistic functions of the temperature. It is an engineering problem and its solutions, to be of use, must have a form which designing engineers can use.

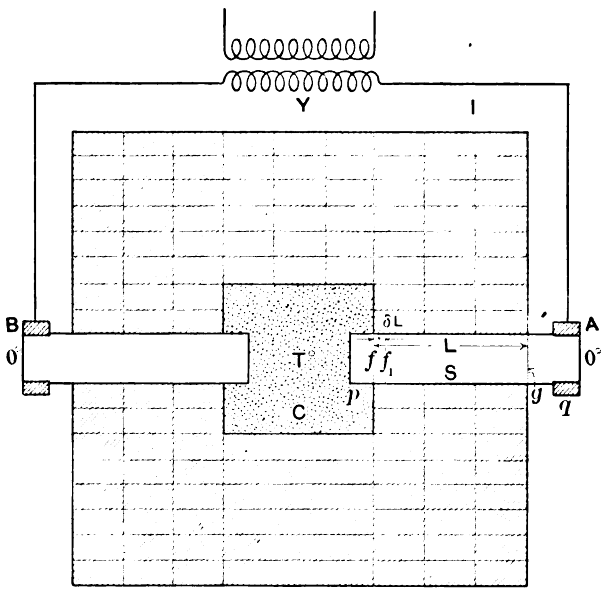
The solutions in Mr. Hering's present paper are set forth in no uncertain or vague manner and are so simple in form that a tyro may apply them in practice. Mr. Hering has introduced for the first time, the conceptions of two new specific quantities which attach to all furnace electrodes. One he calls the "electrode voltage", e, the other the "specific section", S. He points out by reference to actual experiments and theoretical considerations, how these two specific quantities may be determined precisely by experiments upon small test electrodes, and then be used for the calculation of actual large electrodes. When these specific properties of electrode materials, gotten for various furnace temperatures, are once completely determined and tabulated they will have a like value to the designer of electric furnaces that the specific heat of steam has to the designer of engine boilers.

The subject is important, much has been written upon it, and the mathematical point of view has been ably presented by several who are masters in this form of treatment. So much material has been given us that the important, crucial results obtained may still remain obscure to some readers amidst the wealth of material that has been presented. These facts are made an excuse for presenting my way of looking at what appears to me the essential aspects of this interesting subject.

In the accompanying figure the two furnace electrodes A and B together with the charge, C, in the interior of the furnace complete the circuit from the transformer secondary, Y. It is assumed in what follows, that the furnace has been operated until steady conditions obtain—that is, until the heat supplied

to the charge, C, equals the heat lost from the charge, so that the temperature of the central zone of the furnace charge is constant and has the required value, T degrees. It may be premised also, that the thermal conductivity of the electrodes is greater than the thermal conductivity of the furnace walls.

Now conceive that, for a brief time, the electric current is shut off. If this time, when there is no current, is taken sufficiently brief we can consider the interior of the furnace as containing an infinite quantity of heat as compared with the small quantity which will escape in a brief interval. But in this interval some heat will flow through the furnace walls and some through the electrodes. That which goes through the electrodes, per unit of section, will exceed that which goes through the walls



per unit of section, because of the assumed greater thermal conductivity of the electrode material. The heat which flows through the walls must be supplied by electric power to the charge in the interior of the furnace. To reduce this supplied power to the least possible amount involves questions which relate to the design of the containing walls of the furnace and these questions have no connection with the problem of electrode losses.

Only the heat which goes through the electrodes is an electrode loss, which it is our problem to make as small as possible. The electrode, to which the analysis should be applied, is not the physical electrode, extending from p to q (see illustration) but that portion of the electrode f to g which extends the di-

tance L, through the furnace wall. Of course there will be losses in the exposed portion of the electrode (which should be as short as possible) and losses in the contact resistances where the current enters; but these losses require separate consideration, and in no wise affect the problem of the choice of material and the proportioning of the electrode within the furnace wall. The electrode, then, to which this and the other treatments given should in strictness apply, is that portion which extends from the interior to the exterior surface of the furnace wall.

The treatment of the problem would be unmanageable unless it were assumed that the heat which flows through the electrode all moves parallel to its axis. This assumption is thought to be justified for any engineering requirements for two reasons; First, because, when steady conditions obtain, the temperature gradient from the interior to the exterior of the furnace wall is roughly the same as the temperature gradient along the electrode itself. Second, because it is a well known physical fact, that a surface of separation between two unlike substances, especially if the surface is covered with a thin layer of air, offers a great resistance to heat flow. This premised, and being guided by Mr. Hering's analysis, we can reason as follows. The heat-flow in watts which would pass through the electrode from f to g, when the current is momentarily stopped, would be,

$$H = K\,T \tag{1}$$

where T is the temperature difference taken over the length L between the points f and g *at a very brief instant after the current is stopped*, and K is the actual thermal conductance of this portion of the electrode at the same moment.

Now, start the current flowing, which has been stopped but a brief instant. At the moment that the current is started let the ohmic resistance of the electrode between the points f and g be R, and, with the current I actually supplied, let the voltage drop between f and g be E. Then the watts developed electrically in this portion of the electrode will be

$$W = \frac{E^2}{R} \tag{2}$$

This heat is assumed to escape by way of the ends of the electrode only. As its development takes place along the length of the electrode, and is distributed in some unknown manner, it will have to traverse, to escape from the ends of the electrode, a length which is less than L. Suppose when this flow of electric heat is taking place the *effective* thermal conductance of the electrode is K'. By the cooling jacket the end, g, of the electrode is supposed to be kept at the same temperature, but the heat supplied electrically will tend to modify the temperature of the

hot end at a point very near this end so that the temperature at a point f_1, distance δL from f will become, in a brief instant after the current is started $T \pm \delta T$.

Then the electric heat which flows out of the ends of the electrode will be K' $(T \pm \delta T)$, and this must equal the heat supplied, if we assume that the current is maintained steady until steady conditions of temperature are acquired. Hence,

$$\frac{E^2}{R} = K' \, (T \pm \delta T) \tag{3}$$

Now when all the heat (the current being on) which escapes from the cold end is electric heat, no heat will be escaping through the electrodes from the furnace and the loss of furnace heat will therefore be zero. Now fasten the attention on the point f_1, distant toward the cold end of the electrode from f a very small distance δL. If the voltage E is adjusted so that the temperature at the point f_1, is $T - \delta T$, there will be between f and f_1, a temperature gradient toward the cold end, $-\frac{\delta T}{\delta L}$, and some furnace heat will escape from the furnace. If on the other hand E is adjusted so that the temperature at the point f_1, is $T + \delta T$, there will be between f_1 and f a temperature gradient $+\frac{\delta T}{\delta L}$ and some electric heat will flow into the furnace. But this would mean that the furnace had not reached its final temperature which is contrary to the assumed condition of a steady furnace temperature, T. Hence, for no furnace heat to flow into or from the furnace, we should adjust the voltage E, until there is no temperature gradient over the small length δL. That is $\delta T = 0$. and we have from equation 3 for the condition of minimum loss of furnace heat,

$$E = \sqrt{R K'} \sqrt{T} \tag{4}$$

If the product $R K'$ can be shown not to involve the linear dimensions of the electrode, then it is a specific property of the material of which the electrode is made. To do this write,

$$R = \frac{L}{S} \; [\rho_m]_T \text{ and } K' = \frac{S}{L} \; [\sigma_m \, a]_T$$

Then

$$R K' = [a \, \rho_m \, \sigma_m]_T$$

The exact interpretation of these three relations is very important. The first means that the ohmic resistance of an

electrode, when hot at one end and cold at the other, will increase with its length, decrease with its cross-section, and be dependent upon the *average specific* resistance of the material which maintains when the fall of temperature from one end of the electrode to the other is T degrees, the temperature of the hot end being the same as the temperature designated by T in equation 4.

The second means, that the *effective* thermal conductance of an electrode, when heated by an electric current until the temperature of its hot end is T, and when all the heat developed must escape through the cold end, increases with its cross-section, diminishes with its length, and increases with the quantities a and σ_m. The quantity a, depends for its value upon where the center of gravity of the watts developed is located along the axis of the electrode. If this center of gravity is located at the middle point of the axis $a = 2$, if located nearer the hot end a is less than 2, if nearer the cold end a is greater than 2. K' also depends upon the mean specific conductance of the material. This is a constant for an electrode of any size and any particular material when its terminal temperatures are fixed and are produced by an electric current in the électrode. With this understood we have by substituting the value of $R\,K'$ in equation 4,

$$E = \sqrt{a\,\rho_m\,\sigma_m}\,\sqrt{T} = e\sqrt{T} \tag{5}$$

where $e = \sqrt{a\,\rho_m\,\sigma_m}$ is the "electrode voltage" in volts.

It should be noted here that the smaller is a, that is the nearer to the hot end is the center of gravity of the electric heat supplied to the electrode, the smaller is the electrode voltage required for minimum heat loss. In iron, a would be less than 2, in carbon, a would be greater than 2.

The minimum power consumed is

$$P_m = I\,E = I\,e\sqrt{T} \tag{6}$$

Again from (4), writing $E = I\,R$

we get $I^2\,R = K'\,T$ or $I^2\,\dfrac{L\,\rho_m}{S} = \dfrac{S\,a\,\sigma_m}{L}\,T$,

which gives

$$S = I\,L\sqrt{\frac{\rho_m}{a\,\sigma_m}}\cdot\frac{1}{\sqrt{T}} = I\,L\,s\,\frac{1}{\sqrt{T}} \tag{7}$$

Equation (7) is the same as Mr. Hering's equation (7) p. 295, except that the quantity a replaces the factor 2. a will equal 2 only when the center of gravity of the watts supplied to the electrode is at the middle point of the axis and there is no furnace

heat flowing. This will be the case generally only when the thermal conductivity and the electric resistivity are constants.

The quantity $s = \sqrt{\left[\frac{\rho_m}{a\ \sigma_m}\right]_T}$ is what Mr. Hering calls the "specific cross-section". It is independent of the linear dimensions of the electrode but is dependent upon its material and upon the terminal temperatures being assigned at the time its value is determined. Its value will also be different if determined in any non-electrical way other than by the method described by Mr. Hering.

The two equations of Mr. Hering (modified here by substituting a for the factor 2).

$$P_m = I \sqrt{a\ \rho_m\ \sigma_m}\ \sqrt{T} = I\ e \sqrt{T} \tag{8}$$

and

$$S = I\ L \sqrt{\frac{\rho_m}{a\ \sigma_m}}\ .\ \frac{1}{\sqrt{T}} = I\ L\ s\ \frac{1}{\sqrt{T}} \tag{9}$$

the first of which enables the minimum power loss to be calculated and the second the proper electrode section for minimum power loss, I conceive to be the most important theoretical contribution to this subject.

Equations (8) and (9) would be useless if the quantities e and S could not be obtained by experiment. But fortunately, Mr. Hering has pointed out, and demonstrated by actual tests, that they can be so obtained, *and with far more ease and precision* than their components thermal conductivity, electrical resistivity and the center of gravity factor.

The analytical and mathematical treatments, that others have given to this problem, are certainly interesting and valuable in enabling the problem to be studied from very varied points of view. But the following aspects of these mathematical modes of treatment certainly should not go unmentioned. If the thermal and electric conductivities are assumed constant, then the most elemental physical considerations will lead to a solution without any application of the calculus. Such solution, however, is only roughly approximate. If these quantities are assumed to vary as a linear function of the distance along the electrode, then the solution of the differential equation, based upon this assumption, shows that the temperature gradient is not linear and hence the original assumption can only roughly represent the physical facts—probably no more closely than the assumption of constant specific qualities. If the conductivities are assumed to vary as linear or more complicated functions of the temperature, the integrations are at best formidable and generally impossible. An unintegrated differential equation is

at the best nothing more than a formal statement, put into mathematical form, of an unsolved problem.

Respecting this view of the mathematical analysis of physical problems Fourier remarks, (§13, The Analytical Theory of Heat), "The numerical interpretation of the results of analysis is necessary, and it is a degree of perfection which it would be very important to give to every application of analysis to the natural sciences. So long as it is not obtained, the solutions may be said to remain incomplete and useless, and the truth which it is proposed to discover is no less hidden in the formulae of analysis than it was in the physical problem itself."

But suppose one does succeed in writing down and integrating the differential equations which express the conditions of the flow of heat in an electrode. These equations must involve the thermal conductivity varying as a function of the temperature. To obtain, then from the integrated equations numerical results one must know the thermal conductivity of such materials as carbon, graphite, iron, etc., at temperatures from, say, 100 to 2000 deg. cent. These variable "constants" are unknown and to determine them by experiment is *a far more difficult and uncertain undertaking* than it is to measure directly at various temperatures what we want to know; namely, Mr. Hering's electrode voltage, e, and specific section s.

It seems to me that there lies here an important line of investigation, which shall give us the values of e and s, at temperatures up to the highest employed in electric furnaces of all the electrode materials which are likely to be used in these furnaces. Mr. Hering worked with thermo couples to measure his temperatures and did not get up very high. His experimental investigation should be continued, using test pieces of greater ratio of diameter to length, larger currents and higher temperatures than he used. These high temperatures might be quite accurately measured by placing reliance on Steffan's law, that the total radiation from a black body is proportional to the fourth power of the absolute temperature. The radiation could be measured with a form of surface bolometer which the writer has designed and experimented with. This, after being calibrated at moderate temperatures with a thermo couple, could be relied upon to give accurate results at the highest temperatures. A series of values $E = e\sqrt{T}$ and $S' = s\frac{1}{\sqrt{T}}$ could be found thus and tabulated for temperatures exceeding 1500 deg. cent. These constants given by Mr. Hering in table II page 322, are exterpolated values above 950 deg. cent. This was the highest actual steady temperature which he measured, but a platinum-platinum rhodium couple used in connection with a potentiometer could have been used without its destruction to 1500 deg. cent. Beyond this temperature the radiation principle would have to be used, and the results which it would give would be as accurate as the higher temperatures of the fur-

naces are known, as these can only be determined in the same way.

The writer hopes that this more extended investigation may be deemed worth while and he would give it as his opinion, based upon considerable experience in making high temperature determinations, that results of an accuracy entirely satisfactory from an engineering standpoint could be readily obtained in the ways suggested. Such an investigation might be carried out with much propriety at the National Bureau of Standards.

DISCUSSION ON "PARALLEL OPERATION OF HYDROELECTRIC PLANTS." CHARLOTTE, N. C., MARCH 31, 1910. (SEE PROCEEDINGS FOR APRIL, 1910).

(Subject to final revision for the Transactions.)

W. S. Lee: In describing some of the features that enter into the design, construction and operation of our plants here I have endeavored to present them in a general way—in a way which should be considered by every engineer who contemplates a large development consisting of a chain of power plants.

The questions that arise in this kind of work are not always strictly engineering problems. There are commercial and political questions. The problems encountered in this particular section were, principally, a great variation in flow, a scattered market, and a market for power that is used only for a comparatively short portion of the day. I believe that it will not pay to develop an isolated plant in this country, considering the rates at which we have to sell power and the distances over which we have to transmit the power, unless it is a very large one. It is true we have many small powers that can be developed and utilized close by, in cotton mills, many of which have their own plants, but when the transmission field is entered it will not pay to handle these small plants.

While these questions may not be purely engineering problems, they are problems which the engineers of the country must help solve. There is no question that whoever has to operate an isolated plant, with a variable stream, is not going to get power from that plant with the same confidence that he would if he had other plants which he could call upon, or some reserve power. We find that condition in actual experience. With due respect for my own operating department here, I find that it frequently saves the water, fearing that there will not be enough to last through the week, and as a result the water is wasted.

Chas. E. Waddell: I think Mr. Lee has well treated the subject of the economics of parallel operation of plants from the standpoint of the southern engineer, and he has equally well dwelt on the attitude of the public towards these developments. I think he is conservative in estimating the advantages of the investment have been as 5 to 1 wherever a large undertaking of this kind has been made in the South in the increased value of manufacturing sites, manufacturing itself, and of real estate in the vicinity, and I think he might well have added to the paper a corollary on the advantages of such a system to the consumer. Briefly stated these advantages are:

1. With a distribution system such as this, and the use of three transformers connected in delta, a customer has practically a duplicate plant at the cost of one; for, should a line go down or one transformer be destroyed, operation is still possible.

2. The inertia of the large system, once running, is so great that throwing on or off large induction motors does not materially affect frequency or power factor.

3. Uniformity of rates for installations of equal characteristics places all manufacturers on an equal footing, and if competition exists it must be based on factors of cost other than power.

4. The coöperation between a customer and the engineering department of the large hydroelectric companies insures the customer of engineering advice of a much higher order than a small manufacturer would ordinarily have at his disposal.

All of us will heartily agree with Mr. Lee in what he says about educating the public to the great advantages of these systems, and the necessity of passing laws that are equitable and fair and particularly to give the hydroelectric companies greater latitude in the matter of condemnation processes and the right of eminent domain. If I mistake not, it is a law in this state at the present time that power companies have the right of eminent domain for transmission lines. The legislators and the public at large already begin to recognize these interests are public utilities, and should be given powers that are ordinarily delegated to railroads and corporations of that nature. I think it is manifestly fair and right, and I think it is our duty as engineers—because we know both the public's side and the company's side of these questions—to educate the public with which we come in contact to realize the advantages of the universal development of our water resources, their harmonious operation to the advantage of all interests, to recognize the advantage of equality in the rates, and not block development by unjust or antiquated laws that apply to a former age and have no place in the century in which we now live.

Percy H. Thomas: I would like to ask Mr. Lee how the speeds of the various water wheels in the system is maintained, and incidentally, what provision is made for voltage adjustment. And a second question is as to operation—whether all lines of the same voltage are tied together and so protected that any line breaking down will be automatically cut out; or whether the plant and substations are operated in sections, so that if anything happens to one section the lines on this section can be thrown over to another section; or whether separate sections are maintained, the different sections being tied together by instantaneous circuit-breakers? These are three possible ways of operating such a system, and Mr. Lee's experience would be very valuable.

It is interesting to note to what a high voltage this plant is now carried, even though the distances to which power is being transmitted would possibly not demand so great a pressure. I believe it is a very wise arrangement; not only does it give greater efficiency and splendid regulation of voltage, but it provides a large amount of changing current which will tend to neutralize the effect of the inductance of the induction motors, and further will permit a temporary transmission of power through roundabout circuits in case of injury to some main line. Two or three times the normal distance might be traveled,

under such circumstances, without causing any particular disturbance of voltage of serious transmission losses.

There is another side to the problem which Mr. Lee has presented, and which he has of course fully considered—how far is it possible to build up a load whose load curve shall follow that of the water power available. It is, of course, desirable to utilize storage to permit the use of every possible kilowatt-hour from the river, but it is also worth while to encourage the sort of load which follows as far as possible the power available. Possibly Mr. Lee would give us a few remarks on the limitations in the control of the load curve—these limitations, of course, are very great.

What is wanted is some way of using overflow power; as for metallurgical or electrochemical work, or some other way. The ideal arrangement would be some process which can be carried on at night, and which does not require a heavy plant investment; giving some product which has a good steady market value and which is easily shipped. For example, if some fertilizer could be manufactured at night with the overflow current, and shipped in carload lots to the country hereabout, it would be a very great advantage to the power system. Apparently, at the present time there is no such use for overflow power which is really practicable and available. It would seem almost certain, however, that in the future there will be found something which will be more satisfactory.

Considering Mr. Lee's discussion of the advantages of multiple power stations, not only do we gain from having a large number of hydroelectric plants in the same system, but we will gain, as the author has brought out, by having them widely distributed not only three consecutive power houses on one river, but having the power stations on opposite sides of the distribution area allowing the source of power for any particular load to be chosen at will.

Mr. Lee has spoken of the advantage in looking ahead in laying out a large power system. There can certainly be no question about the wisdom of that principle. I think it is also true that every big power system, like every other large undertaking, is an evolution, and must have its growth guided by its past experience; and if we start with a central idea which appears best at the time, it is not wise to determine conditions too far ahead, because conditions are likely to change, and it will be better to have the development flexible enough to take advantage of the situation existing at the time of action.

D. B. Rushmore: A feature of Mr. Lee's paper deserving of particular discussion is the use of steam auxiliary plants in connection with large hydroelectric systems where the power stations are developed to a point above the minimum flow of the streams. In a few localities, such as Niagara Falls, steam auxiliary plants are needed only as an insurance against breakdown of transmission lines. Such plants may, however, perform various func-

tions, such as taking the peak loads, of supplying the wattless current of the system, etc. At the present time the development of a hydroelectric system necessarily involves the use of such steam auxiliaries.

A. M. Schoen: The points of advantage to be derived from the parallel operation of hydroelectric plants, as explained by Mr. Lee in his very able paper, are too self-evident to need discussion, but if these advantages accrue from tying together a single group of plants in a fairly circumscribed area it would seem that the extension of the same system over a wide area would accomplish results even more to be desired. One of the principal factors justifying the arrangement recommended by Mr. Lee is the fact that if, with several plants so grouped together, each stream takes its water from a different drainage area, there will be a greater tendency towards flattening out the primary power curve, thus increasing the salable primary power against the corresponding decrease in the secondary, as extreme low water in two well separated basins at the same time is unlikely, and this improbability continues to increase with the number of streams drawn upon and the increased separation of their drainage basins.

Take, for instance, one of the southern counties, the commissioners for which recently requested me to formulate specifications under which four competing hydroelectric power companies should be permitted to run their transmission and distribution systems. Two of the companies were located at adjacent points, on the same river, while the other two were supplied from entirely different streams, taking their rise and supplementary supplies hundreds of miles from each other and from the first river. Any arrangements between these four companies by which they might supplement each others' power in extreme cases would seem to be mutually beneficial, as such an arrangement would result in increasing the salable primary power to a greater or less extent for all four without calling for additional equipment, except in the pole lines, assuming, of course, that all were using the same voltage, periodicity and frequency. This serves to accentuate the particular point I had in mind when rising to discuss Mr. Lee's paper, namely, the need for conforming to some general standard when installing plants of this kind, for in my opinion, the time is coming when there will be some general working arrangement, even if the ownership is different, between plants of this character operated in the same section of the country. Indeed, it is hardly too great a stretch of the imagination to say that the time may come when sections rich in water power, such as the Piedmont section of the southern Appalachians, will be covered by transmission lines fed at intervals from the various power houses, thus creating one large interdependent system furnishing a maximum primary power supply to the country within reach, and under the most advantageous conditions both to operator and consumer; and should this occur,

the next step in natural sequence when such relationship between the properties existed would seem to be an arrangement of dams across streams at judiciously selected points between the mountains, resulting in the impounding of these waters by means of artificial lakes and a consequent increase in the water stage of the streams affected with corresponding increase in primary power.

Carl Hering: Regarding the utilization of electric power from hydroelectric plants at such times during the day, night or year when there is plenty of water and a light load, there is probably no better way to utilize that power than for some electrochemical or furnace processes which can be started and stopped at prearranged times, and which require large amounts of power but must get this power very cheaply in order to make the processes commercial.

It seems to me that this has not been given the attention which it deserves. Such power could be delivered very cheaply, yet with great profit, as the cost of it to the producer is extremely small because this cost should be charged with only the difference between the cost of operating with and without this extra load. If power at such low costs were offered at prices agreed upon for reasonably long terms, it would probably find a sale when the offer became generally known.

Even a furnace might be operated during a limited period every day, if enough current could be obtained during the rest of the day to merely keep it hot; and when furnaces are designed and proportioned more carefully to reduce the heat losses, as they undoubtedly will be after it becomes known how to design them properly, these stand-by losses ought to be reasonably small. A case has been reported in which this was profitable even when coal was the fuel, and it would therefore be much more so when the source is an excess of water, and when it becomes possible to design the furnaces more correctly.

H. N. Muller: It might be of interest to the people here to know that power is now being used in the off peak periods in the Pittsburgh district for the manufacture of steel, or rather the refining of steel that has been preheated and somewhat refined in the open hearth furnace, or made from the scrap, at a cost of about one cent per kilowatt-hour for current. This has been carried on for over a year, and while I do not know what the manufacturers' profit has been on this steel, which is used principally for high grade tool steel, they are still completely equipped with crucibles, and I feel they would revert to the former methods if the electric furnace was not more profitable.

W. L. Waters: Mr. Lee's paper deals in a complete, though brief, manner with the fundamental engineering and economic questions connected with hydroelectric power distribution. The only suggestion I wish to make on this subject is that the induction type of generator should be considered more frequently for such installations. The disadvantage of operating a large num-

ber of small power stations, is the increased expense due to the attendance required for each station. In large city power stations it has been found more economical and advisable to operate power stations of 100,000 to 200,000 kw. capacity, when the conditions in regard to the magnitude and location of load justifies such a size. In a well distributed water power system such as Mr. Lee has referred to a power station of this capacity is usually impossible as the water power is not located at one point.

The induction generator consists of an induction motor operated above synchronous speed, and the advantage of this type of machine is simplicity of construction and operation. The induction generator does not require any direct current exciting system or complicated switching gear. In addition there are no governor or parallel-operation troubles and the units once put on the line can take care of themselves, the load being regulated by the governor of the prime mover. The objection to induction generators is that they require a wattless magnetizing current which must be supplied by the system. Just as an induction motor takes a wattless magnetizing current from the line and delivers mechanical power, so the induction generator takes wattless magnetizing current from the system while it supplies the watt component of the whole.

Two years ago I presented to the Institute a paper on the induction generator as applied to large power station work. In this paper I dealt mainly with the application of this type of generator to large power stations operating a considerable amount of synchronous apparatus, and the question of such units in connection with large water power systems was only briefly touched on; the reason for this being that there was practically no large overhead transmission system operating with the high voltage at which the Southern Power Company is operating at the present time. The possibility of operating large overhead systems at 100,000 volts changes the situation completely. Mr. Fraser states that the capacity charging current for 140 miles of the Southern Power Company's 100,000 volt line is about 7,000 kilovolt-amperes. These 7,000 kilovolt-amperes will supply the full load wattless magnetizing current for 20,000 to 30,000 kw. of steam-turbine-driven induction generators or about one-half that capacity of waterwheel-driven units. Mr. Lee will tell us the Southern Power Company expects within the next five years to have the 100,000 volt line so extended that the charging current will probably be increased to 20,000 kilovolt-amperes. If this is the case the overhead system would be capable of supplying the full load wattless magnetizing current for from 30,000 to 100,000 kw. of induction generators, the exact capacity depending upon the speed and the voltage at which they are operated.

The commercial history of the induction generator has been comparatively brief. The first application of any size was a

1200-kw. unit installed in the Baltimore Copper and Smelting Rolling Company's plant about six years ago, while recently three larger units have been installed in the Interborough Rapid Transit Company's power station in New York City. The generators in both of these installations supply power to rotary converters which transform the alternating current to direct current. The induction generator appears to have been somewhat neglected in the past because the conditions were not favorable to its adoption. The necessity of a wattless magnetizing exciting current which must be supplied from the system, is a great disadvantage in a number of cases. But with large city power stations operating synchronous apparatus, or an extensive high voltage overhead transmission system, with large capacity charging current, the conditions are much more favorable to this type of generator. In any system such as that of the Southern Power Company the arrangement suggested would be: synchronous units installed in one or two of the large power stations and induction generators in all the smaller stations. The generator units in the smaller stations would run continuously on the circuit without attention, the governor of the prime movers regulating the load, while the voltage on the system would be controlled from the large synchronous power stations. The suitability of the induction generator for any such system would depend to a great extent on the speed at which the units operated, the voltage for which they are wound, and the power-factor of the load on the alternating-current distribution system. And, in any case, the advisability of adopting or not adopting such an arrangement of induction generators in any large complicated system such as that of the Southern Power Company could only be decided after the system has been laid out in detail, and all the economic and engineering features been given due consideration. My object in bringing forward the induction generator at this time is not that it is considered advisable to adopt this type of generator universally in such installations, but that as conditions are gradually changing and becoming more favorable to the adoption of this type of unit, it now deserves more attention than it has received in the past.

Chas. F. Scott: Mr. Lee's paper besides presenting the general conditions confronting the Southern Power Company, shows also a new stage in the development or evolution of electrical transmission.

The high tension transmission system of several years ago consisted of a generator, raising transformer, line, and a lower transformer with some distributing lines. The transmission system consisted of a single transmission line from one generator to one substation. More complicated designs rapidly developed. In one type a number of power plants supplied a single point; possibly Los Angeles may serve as an example which receives incoming power from several directions. Then, again there is another type in which power is generated at one point

and is distributed by various transmission lines in different directions, each of these lines supplying stations at various points en route; Niagara Falls is typical of this condition.

In the case of the Southern Power Company we are apt to think that operating at 100,000 volts is its great feature, but a statement of Mr Lee's shows that there is something more notable. He says now that this is not a high-tension transmission system, but a high-tension distribution system. There are many scattered power houses, and many distribution centers.

A number of years ago, when the Niagara plant was being laid out and great interest was concentrated on the generators of mammoth and unique form, one of my colleagues, who was engaged in the development of switching apparatus, made a remark which struck me on account of its originality and novelty. He said that the great difficulty and the big problem in large electrical work would not be in the generators, but in the switching and controlling apparatus.

I have thought of that remark many times since, and I believe it is more true to-day than when it was first spoken. In a plant with high-pressure circuits and many receiving and distributing points, such as has been described this morning, the problem of switching and controlling apparatus constitutes the large electrical problem. So that this plant illustrates, not only the new commercial-political relations, as Mr. Lee has pointed out but also marks a new stage in electrical operation and the types of apparatus which are required.

In brief, the operating conditions, the inter-relation between stations and operators, involving such questions as those Mr. Thomas asked, and such questions as Mr. Waters brought out a moment ago in their discussions—these are the large and important elements upon which the success of the plant will depend.

The relation of electricity to the conservation of energy is one which has received attention at the hands of our President in one of his papers before the Institute, and it seems to me Mr. Lee has brought out some features which are descriptive, in a large and broad way, of the larger service which electricity will have in the conservation of our natural resources. It not only saves the waste of water power and enables it to be utilized, but by entering into a whole region, by making a power system of a whole state, it equalizes the different variables which occur in the operation of each individual system which Mr. Lee has pointed out. Now, by interconnecting many plants into one general electric system covering the whole stage, these individual elements or variations can largely be wiped out, and we can get that general average which means the highest general efficiency, so that we equalize power, and we save power, and furnish a better and cheaper power, as was brought out in the discussion yesterday.

With regard to the relations of the engineer to the general

problem, I would almost disagree with Mr. Lee, when he apparently limits the function of the engineer to the purely technical problems. He says in the beginning of his paper that some of the problems are commercial rather than engineering. Taking our natural resources, and applying them most efficiently under the conditions which exist, I think, like most of the things which he has brought up, can properly be placed under broad engineering. I think he is right also in stating that the proper way for engineers to handle the large conservation problem is by attacking the problem in a large way and getting efficient results. And I believe that the general common sense of the American people is such that they do not object to having things done in a large way on a sound engineering basis, but what they do object to is having them done on a false and unjust social and commercial basis. Our commercial and political friends should recognize the same kind of standard that the engineers work to, high efficiency, the greatest good to the greatest number, on a fair and just basis; in fact engineers are setting the standard of principles which should be adopted in commercial and political life, as they must practice them in their professional life.

In talking with one of the older men in this community, who has seen things build up in the South for many years, and in speaking of the new life which has come to the district, and the new methods in cotton mills, he said that pioneer work of this kind requires imagination, initiative, and nerve. He said that is what the Southern Power Company has, and I am sure we all agree with him.

Edw. W. Shedd: Mr. President and gentlemen, I have been exceedingly interested in the paper that has been presented by Mr. Lee, and I desire to offer just one suggestion which I think has not been touched upon in the discussion, but which Mr. Lee brought out in his paper, and that is the great importance of the question of transportation; and I am sure that you will all agree with me that that is a question of transcendant importance, and it is a question which must be met and worked out if the fullest development of our southern water powers is brought to pass, and it is a question which I think works in most uniformly and nicely with the question of hydroelectric development.

For nearly two years I have been working in this territory, purposely selecting the territory in which the Southern Power Company is operating, upon a system of railways which is designed to meet the needs of the territory as regards transportation, and which I think in the near future is bound to be built.

I want also to emphatically endorse the suggestion of Mr. Lee and others who have discussed the paper as to the value and importance of engineers and every one else educating the public, especially perhaps the political public, as to the advisability of giving to these quasi- public corporations sufficient rights, particularly in the way of eminent domain, to enable them to

carry out all their important developments which are in progress. It seems too bad that many valuable developments are held back by the narrow mindedness of some one man who thinks he has a big corporation to deal with; he will get fifteen times the value of his land, just because the corporation wants a right-of-way through it. Such procedure holds back development in many cases. It is the duty of every electrical engineer and civil engineer, lawyer and banker, to try to educate the public and to work with the legislators, so that a broad-gauge policy can be followed in these matters.

Speaking directly to the point, it has been suggested that we should develop something that would use the water power when the hydroelectric companies have a surplus of water, and when it is not being used for other kinds of business. It has occurred to me to-day, and it has occurred to me many times before, that one very large use, possibly of this power in the night time could be developed by operating a system of railways, particularly in the section of the country in which the Southern Power Company and other hydroelectric plants are operated, hauling the freight in the night. A large amount of power can be used at night in hauling freight, for I see no reason why the freight business could not be done in the night time when there is a surplus of hydroelectric power available. It is my purpose to use hydroelectric power for the operation of railways in the district of the Southern Power Company, carrying freight at night.

Perhaps this is not the place to bring it forward, but the idea has occurred to me that it might be desirable, if it were constitutional to subsidize such industries as water power developments, railways, etc., in the way, possibly of exempting their bonds from taxation. It might be possible in this way to induce the banks and trust companies in the south, which are pretty well supplied now with money, and find difficulty in lending it, to take some of the bonds, of these enterprises as this would make them more attractive as an investment.

It has occurred to me that this might be done by the partial or complete exemption of taxation on bonds issued by hydroelectric plants, and on railways, exclusively within the state of North Carolina, and held, perhaps, exclusively by investors residing in the State of North Carolina. It looks to me as though something of this kind could be worked out very satisfactorily, and this would make the railways and the hydroelectric plants, as you might say, a board of trade, which would be working for the development of the entire country, and at the same time furnish a more attractive investment for the money on deposit in North Carolina, to be used only in this State, and in other states, if such states do the same thing.

President Stillwell: Mr. Scott has already referred to the first of the points which I noted in listening to Mr. Lee's paper, namely. his apparent contrasting of the ideas of engineering

considerations and commercial considerations. Engineering, as I understand it, when applied to the solution of these large industrial problems, means the application of commercial business judgment, reducible to terms of dollars and cents, to those problems; that application being based, however, upon special study of the technical underlying problems which are essential as a foundation for the general solution. I think if we were to use the words "technical" and "commercial," in making a contrast, rather than "engineering" and "commerical," we should place the matter in about the right light, because we do not want the community to get into the habit, which I am sorry to say it has acquired in part, of looking upon engineers as men who are incapable of drawing practical deductions. The engineering which is of the broadest kind, is precisely the kind which Mr. Lee himself, a member of the Institute, is carrying on. He has applied broad business judgment, based on technical knowledge, to the solution of industrial and commercial problems. Immediately, that raises a question of engineering responsibility, and that is a point I want to say a word about.

We have now throughout the country an abnormal number of hydroelectric enterprises in the hands of receivers. In every case that I have had occasion to investigate or have learned about, and I have come in touch with a number of them, the failure has been due to the fact that at the outset the proper kind of commercial-engineering brains were not brought to bear on the problem. I do not know an important case where the thing that caused the enterprise to fail could not or should not have been foreseen. Engineers are too apt to allow themselves to be hurried and pressed by the promoter. In one important case where an estimate had to be revised to an extent which involved the raising of about $2,000,000 in addition to the original amount provided for by the financiers, I am told that the engineer made the excuse that he was allowed only one week to investigate that problem. That excuse is an indictment of the engineer himself. Any man who could undertake to pass on a matter involving large amounts of other people's money, or small amounts, on a matter of such magnitude, in such a short time, ought to resign from the engineering society and get out of the business. He does not belong there.

Mr. Lee made reference to the subject of condemnation of rights for transmission lines, and also of the lines which are essential to the hydroelectric development. Now, there is a point where I believe we can use our influence, not collectively, perhaps, but individually with our congressmen and friends in the legislatures, in a perfectly proper manner, and in a manner that will redound to the benefit of our engineering organization and of engineers as individuals and of the community at large. We have in the country two classes of public utility corporations, aside from those which have to do with the cities, the gas com-

panies and the railways, and now we have to do with these great transmission and distribution systems utilizing water powers. The railways have the right of eminent domain. In general, the power companies have not. Is there any possible reason and logical common sense why they should not have this right? The gross earnings of the railways of the United States are approximately $3,000,000,000, a year. The gross value of our manufactured products is approximately $20,000,000,000 a year. This utilization of power means a general tendency to decrease the cost of the manufactured product. It also means in many cases, and in more cases to come, a reduction in the cost of transportation. Economically considered, therefore, every reason that exists for conferring upon the railways the right to condemn, exists with increased force in the case of the power companies distributing energy for the very many purposes to which the community applies it. Now, this question of natural monopoly must be met, and we must meet it with an effective answer. As citizens many of us are lined up on that side of the question, but we have to face the fact that, at any rate, there is going to be in this country government regulation of rates, especially the rates of public utility corporations. The right of the state has already been upheld in the case of the Consolidated Gas Company in New York, where the decision of the supreme court of the state of New York was appealed to the United States supreme court, and in that case it was definitely decided by the higher tribunal that the state has the right to regulate rates. Now it seems to me that the answer to give to those people who are objecting to a natural monopoly in water power is this—that it is absolutely unnecessary to retard the development of these enterprises at this date, for the reason that just as rapidly as they place themselves in the position where they are imposing upon the community by charging excessive or unfair rates, the state is in the position to intervene and regulate these rates. This practice of conjuring up something that might happen in the dim and distant future in the way of fixing rates is too remote an excuse for justifying any possible retardation in the forward movement of this extremely important conservation, because conservation is, in this case, most emphatically utilization; but we must have our answer, and the answer is not that our rates are moderate—they won't believe it. We can give that answer to those who will believe it, but most of the people will discount such a statement; but our answer should be this—that just as soon as this is a real danger, and not an imaginary one, the state can intervene, as established by the decisions of the supreme court, and fix just and equitable rates.

I think it is the duty and a part of the business of engineers to take a hand in public affairs. I do not see why 20,000 engineers in this country should sit back and let other people, five per cent of whom do not understand the facts necessary to the commercial solution of these problems, pass upon them, while

the engineers sit on the fence and watch them do it. The engineers should get into the game early and meet the people who are interested in these things in a social way, and otherwise, and endeavor in every possible way to educate them. That is what they need. We have talked with many of them, including Mr. Ballinger and Mr. Pinchot, and have seen none of them who do not admit that they need ideas in regard to the practical, technical and economic bearing of some of these questions, which some of us are able to give them.

W. S. Lee: Referring to Mr. Thomas' remarks, he asks about the speed of wheels. We have on the system different heads, different size ponds, and consequently the plant with the small ponds must be run a longer number of hours, and in the case of the larger ponds a shorter number of hours, but with a larger peak load. All the waterwheels permit a certain variation of head and maintain the same frequency. We endeavor to reduce these heads as little as possible, it being our practice in extremely low water to put in our steam auxiliaries in the early part rather than in the latter part of the week. While originally we had the idea that we would run the water as long as we could, and at the end of the week put in the steam to help out the week's load, we find by keeping the head up in the earlier part of the week we get more power out of the system.

Mr. Thomas also asked about voltage regulation. In order to meet the conditions with which we were confronted, that is, differences in voltage, we got out a standard set of specifications giving a list of taps which we were to have on all of our high tension transformers. This calls for a higher voltage to be run on the plant during the time of our heavy load hours. When the load goes off the cotton mills at six o'clock in the afternoon, the voltage on the whole system is lowered. This takes care of the drop in voltage in the line, the transformers being tapped with reference to the distance from the power house. The line which it is hardest to control the voltage on is the line that is not loaded.

Mr. Thomas also asked some questions about sectionalizing the system. I will say that that is a question which I have been dodging in a way. We have certain lines that go to stations or distributing points. We term them switching stations. From these switching stations the lines may branch out into a greater number of lines to cover different territory. We then go on to another point and break the line up into several more lines, supplying different points. All of these stations are provided with automatic switches or fuses. We can sectionalize the different parts of the system from time to time, putting one plant either on one side or the other.

Mr. Thomas also is rather disposed to criticise the voltage we are going to, but I do not think I will answer that because he answered that point himself. He stated that perhaps it would be a good thing to use these higher voltages to run around and come back over greater distances, where there might be a reason

for doing this. That is what Mr. Burkholder does. It is fifty miles from here to Great Falls, and Mr. Burkholder does not hesitate to take the current to Salisbury and back again, and by the time it reaches Charlotte it has traveled 150 miles.

Mr. Thomas also asked some questions regarding the distribution of load. That is a question we do not know how to answer. You may have an idea that one particular section of this system is going to develop and you will be surprised to find some other develops much faster.

Regarding the remarks he made as to the location of plants on the outskirts of the district, that is not possible, because the bulk of the power is brought up country and there may not be any water power in that particular district.

Mr. Rushmore referred to steam auxiliaries and synchronous condensers. In connection with that, I will say that we are now installing some of this apparatus at Greenville, South Carolina; we are installing a 10,000-kw. steam-turbine, which will operate as a synchronous condenser, and we are arranging to install another similar set at a point we have not yet decided upon, which will have a capacity of 6,000 kw.

DISCUSSION ON "PRACTICAL METHODS OF PROTECTING INSULATORS." CHARLOTTE, MARCH 31, 1910. (SEE PROCEEDINGS FOR MARCH, 1910).

(Subject to final revision for the Transactions).

President Stillwell: Gentlemen, we have listened to a very interesting paper on a device which I believe is quite new in the art, and original with Mr. Nicholson or his associates: a device that, aside from the results obtained in connection with the plan used in the Niagara Falls construction, will probably be tried in many other instances. At any rate, it appears to me highly suggestive and important in this connection. I believe that if the attention of our designing and operating engineers can be concentrated in respect of overhead transmissions, on the subject of automatic limitation of the destructive effects of a short circuit, results of great value can be accomplished.

I recognize fully the enormous difficulties presented, but they are no greater to-day, apparently, than the analogous difficulties which we faced twelve years ago in connection with underground work, and to-day the underground cable systems are equipped with automatic devices which protect the service so that when a cable fails the only indication of that fact is given by the recording instrument at the power house and the substation. In the case of the Interborough system in New York City, there are, I think, five hundred miles of 3-phase cable in service operating at 11,000 volts. The difficulties that troubled us greatly five years ago are substantially eliminated, and the last time I asked Mr. Scott, who is in charge of the operations of these plants, about his interruptions of service, he said he had forgotten the subject. The records showed they had seven failures of cables during the previous year but not one of them caused an interruption of the service.

In the case of the Southern Power Company, where networks of distribution are being built, it will be possible some day, perhaps even now, to use automatic circuit-breakers in a way which will reduce very materially the commercial interruptions resulting from lightning or other short circuits on the line.

F. P. Catchings: I think in many respects that this paper which Mr. Nicholson has presented this afternoon is one of the most important we have listened to at this meeting. For one reason, particularly, I think so; the problems and difficulties of obtaining the money and financing transmission systems or power plants, and then putting them together, building them after we have obtained the money, you might say are more or less minor difficulties, which we understand and which can be overcome, but the effects of lighting and allied phenomena are rather more obscure, and one of the prime necessities, if not the most important requirement, is to keep these plants in operation —to see that there is a continuity of service. I think the statement in that connection given by Mr. Nicholson sounds

the key-note of the whole situation where he says: "No plant comparable in extent and type of construction with the one under consideration was discovered which did not have to contend with the shattering and puncturing of insulators by lightning, as well as with occasional short-circuits during lightning storms." I think that right there, in that paragraph, is a challenge to the electrical engineers of this country, because no matter how much money is invested in the plant and distribution system, unless fairly constant, or nearly constant service can be given, it will not be as successful as it would be otherwise.

The company with which I am connected attacked this problem of insulator puncturing and smashing in a manner similar to that undertaken by Mr. Nicholson, except that we placed the horn gaps on the towers, about 500 feet apart, previously trying the plan of building horn lightning arrester stations every mile or so, and we found, as Mr. Nicholson did, that insulators would puncture on the adjoining tower, within five hundred feet of a five-inch or six-inch gap to earth, so that these discharges and surges were probably of such great frequency that they would not travel 500 ft. of the copper cable, but would discharge through or over an insulator; a horn gap was then placed on every insulator. The line is about fifty miles long, 50,000 volts, Y-connected, and there are some 1,500 of these gaps on the line. They are spaced about five inches, there being approximately 30,000 volts difference of potential between the two horns. We have had the horn gaps on two years or more, and in that time only lost two insulators. One of these was weakened by having been shot with a rifle, so it was not full strength, and the other was punctured through the top. As Mr. Nicholson brought out, it is much more desirable to have momentary fluctuations in voltage or winks of voltage in the line than to have an insulator punctured or smashed and be shut down for several hours. The customers will stand the winks far more readily than they will the shut-down.

There is one question I will ask Mr. Nicholson; is there any drop in voltage caused by the discharge between his arcing-rings?

J. W. Fraser: It seems to me that Mr. Nicholson's solution of this matter is a very good one, and I think you will all agree with me that he has given us something which will be of lasting benefit. He has found a way to protect the insulators, but he has not yet discovered any way of preventing short-circuits.

I was glad to hear our President say that he expects in the next few years to see a distributing system so equipped with automatic circuit-breakers as to be able to cut out lines which were hurt by lightning or in any other manner. I think we need such automatic regulation very much. It has occurred to me several times and has been impressed upon me lately, that the factor of safety in insulators is entirely too small, and I should like very much to hear the opinion of the transmission

engineers here in regard to this point. It is customary to use a three-part insulator for 50,000 volts, and a four part insulator for 66,000 volts, and any one who has done any testing on insulators knows that between 50,000 and 60,000 volts, as a rule is all that can be depended upon for one piece of porcelain. It seems reasonable to expect that interruptions could be greatly decreased by increasing the insulation of transmission lines. When we step, say from 50,000 to 100,000 volts, we practically cut the copper to one forth the original area, and we believe that part of this saving could be well invested in insulation. I have been making a rough mental calculation, and I find that doubling the insulation on a 100,000 volt line, increases the entire cost of the whole system about 7.5 per cent. If this extra investment would cut the interruptions in two, the money would certainly be well spent.

E. E. F. Creighton: The protection of insulators is one of the problems that has not received enough attention. It is the most important one in protection at present. The problem of the protection of apparatus against lightning is solved. The information and data given by Mr. Nicholson is of great value.

One thing particularly that needs comment, and needs the assistance of all transmission engineers, is the subject of the spill-over of the power from the insulators, with strokes of lightning, not on the line, but near the line. Mr. Nicholson gave two cases only where the lightning stroke was about a quarter of a mile from the line, that caused flash-overs of the insulators. He gave another case, where the distance, I believe, was seventy feet, on an adjacent telephone line, and that also caused flash-overs. Up to the present time the use of the overhead ground wire is about the only protection advocated for lines of moderate potentials. This particular system has no overhead grounded wire, and it would be a very valuable thing to know whether a stroke as near the line as 70 feet would have caused a spill-over on the insulators if overhead grounded wire had been installed for protection.

It is difficult to get information on this subject, and I would like to suggest one definite method of study—that is by photography. During night storms point a camera in each direction along the lines, at a point as far above the line as possible; change the film after each flash, note whether it causes a flash-over of any of the insulators, and note also by means of station recorders the simultaneous disturbance in the station, especially of the lightning arresters. At the present time there is being put on the market a definite discharge recorder, which will record the exact time when a discharge takes place in a lightning arrester, also tell the phase in which it occurred, and whether it extended to ground or not. It will also give a measure of how long the discharge continued through the lightning arrester and an indication of the current or quantity of electrolyte by the size and nature of holes it bores.

I will ask Mr. Nicholson whether he has any further information of the effect of strokes near the line in causing spill-overs.

If lightning strikes directly on a pole or tower it seems evident that a discharge must take place over an insulator of the power line—even if an overhead grounded wire is used.

J. S. Jenks: My intention is not to discuss this most important paper this afternoon, but rather to give you a few conditions which the West Penn System has overcome and some slight idea of our methods of determining the cause and rectifying same, giving us reasonable protection and practically the same effect that Mr. Nicholson has obtained in his plant.

In the first place we started with the lightning arrester. We made very exhaustive tests and records. We not only recorded the time of each discharge on record sheet, but also the phase and the territory in which the discharge occurred. We have continued this record up to the present time and expect to continue it indefinitely, to a certain extent, in that we keep a record of every arrester which discharges; a record of every storm which occurs and when it reached each portion of the system. We also have a telephonic report from each station on our system telling of the coming of a storm. This places the operating force in position to be ready to manipulate any switches or make any changes in the operation which we think essential.

Our transmission system consists of a loop of 185 miles of line, divided into seventeen sections and fifteen substations. Each section is protected by relief gaps and disconnecting switches as it enters and leaves the substation. Just inside of the substation wall it is protected with a lightning arrester; then it passes to the automatic switch and to the bus. The buses have disconnecting switches in the center, making it possible to divide the system at any point, operating one-half the system from either direction. This makes a flexible method of cutting out any one section that is in trouble.

We experienced trouble from the flashing over of the insulators, where we were protecting railroad crossings with grounded pins and arms, in line with railroad specifications. The majority of our construction is wooden poles, wooden arms and pins, where we have had no trouble from flashing over. We overcame the flash-over troubles by taking a lead from the top of the insulator to one side, letting the discharge go to the grounded arm a safe distance from the insulator. We found this advisable, rather than letting the discharge strike from the line, on account of the trouble we had with aluminum, due to burns. I notice that Mr. Nicholson's experience with aluminum due to burns has been different from ours. We have had numerous lines down—in fact, three cases of trouble before the current was put on the line, due to burns from lightning.

I have brought with me a few samples, which I think some of you may be interested in, showing results of small burns on aluminum wire. We did not test or change the insulators, we

obtained our relief without any such expense; as Mr. Nicholson says, it was expected to get relief, from the second line, by simply putting in a discharge gap. I trust the relief will prove satisfactory and justify the risk. The possibility of increased business on the strength of continuity of service is a matter that has been very serious with us. We are in a gas field where we are competing with natural gas sold as low as four cents per 1,000 cu. ft. for power, and twenty-five cents to any person who wants it in the smallest quantity. We have been able to bring our time efficiency—which is based on the effective kilowatt capacity—from about 80.2 up to 99.996. Those last two nines were very hard to get. We have been able to bring it up to this high standard simply by having the automatic devices kept in perfect order, inspected at regular intervals and tested. When we get a case of direct stroke, or something of the kind, we frequently have the section between two substations dropped out of service; we try closing the line breakers; if we get a short-circuit or ground the line is left off and inspected. We have a great many strokes, spill-overs or surges caused by some stroke in the vicinity, which are simply relieved without any interruption whatever.

A word in regard to the factor of safety on insulators. Our transmission carries 25,000 volts. We have, after some little season of experiments, raised our factor of safety higher than the majority of people. We endeavored to get a factor of safety of five on the insulator we used, never putting on an insulator that has a factor of safety less than four. Sometimes the manufacturer will fail to be able to give us five as a straight run, but we compromise and take anything that is not less than four. That is a standard a little higher than most company's.

As to the possibility of direct stroke in the vicinity of lines, we have a record in our office which shows that we had three poles shattered by lightning and knew nothing of it, did not even have a surge. These poles support two three-phase lines, the lines being arranged with the long arm on top, the wires equilaterally placed, and the apex at the bottom. The poles were shattered between two wires only thirty inches apart. So far as we know, that actually happened without even giving a disturbance of voltage. The way we arrived at that conclusion is that our inspectors, who inspect and make records of everything which they find on the line, the condition of every pole and every little chip out of an insulator, etc., inspected the line one day and reported the line in perfect condition; two days following, a very severe storm in the meantime intervening an inspector reported three poles right together which were shattered where the lines crossed over a telephone line. We considered very seriously the matter of overhead ground wires for guarding our line at one time, when we were having the majority of our trouble, but after some experiments with iron wire and fixtures in the coke region where the detrimental effects of the sulphur

fumes on the iron wire are prevalent, it was decided to let the grounded wire and fixtures necessary to support the same alone, and go to an increased factor of safety on our insulator, and have some relief gaps for the line.

C. F. Scott: There are two sides to this paper, one that has been presented by Mr. Nicholson, recounting the history of different ways of doing things and results obtained, and another, looking at it from the standpoint of the kind of problem which was presented some two years ago to the transmission company with which he is connected. The conditions are something like this: The company had its important line in service, the insulators were proved inadequate, the exigencies of speed in construction had necessitated putting up insulators without complete tests, and the best thing under the circumstances was probably to do as it did, although it had to take certain chances. It was found then that some of the insulators on these lines, which extended out hundreds of miles, were breaking down. More than that, it was found that when the insulators themselves were possibly in good condition, the conditions were such there would be a flash-over even on a perfect insulator which might destroy the insulator. One of the first requisites was to determine some method of finding the bad insulator, which might be one mile, or ten miles, or fifty miles out on the line, it being almost impossible to see by inspection if they were punctured or not.

The result was the invention of the very elegant method of locating defective insulators described in a paper by Mr. Nicholson before the Institute some two years ago. Now, Mr. Nicholson has pointed out how very difficult it was to make tests of insulators on the line and to replace the poor ones. Different methods were tried, spark gaps were put up at intervals on the upper wire, which was the one which was damaged most often, and yet this proved inadequate. What was to be done? Most of us would condemn the insulators and say that new insulators should be provided, but it was impracticable to get new insulators at once. Mr. Nicholson took the conditions as they were, and in a way which now seems simple, and obvious after you see it, but not before you see it, he made this simple addition for the protection of the insulators, meeting an emergency, which was a very serious commercial condition. It is not a matter for laboratory tests in which it makes but little difference whether the result comes out one way or the other, but it was a very serious emergency condition on a very important transmission line which must be in continuous operation, where the facilities for making tests were very meager. And under these conditions, leaving the insulators as they were, he has devised a method for the protection of these insulators; and the simpler the method the greater the ability required to discover and apply such a method. The idea of putting some kind of a spark gap or lightning rod all around the bottom of an insulator is rather ridiculous when proposed at first, but it is because he

has taken that simple and ridiculous thing, and gone ahead and accomplished a notable result that I think marks one of the greatest strokes of ability in the work which he has done.

Most of the pictures of insulators do not look formidable in size, because we have nothing to compare them with, but on one page in Mr. Nicholson's paper we see a piece of an insulator placed alongside of a barrel, and we see that it is about half the size of the barrel. The size here is about the limit, it seems to me, in physical dimensions and weight which is permissible for the upright pin insulator. As we go to these higher voltages new elements come in which are not found with the little insulators. This matter of flashing over and breaking off petticoats is a thing that has come up in the larger insulators. Again, in the three-part insulator, the distribution of potential within the insulator, which Mr. Nicholson pointed out, becomes a serious matter. The different parts of the insulator, which are cupped one inside the other, do not distribute the voltage uniformly, but the inner part of the insulator, next to the head of pin, probably has to sustain an e.m.f. of twice as much per tenth of an inch, as that toward the outside, and it is a remarkably fortunate thing that the new distribution of potential caused by the placing of the protective rings tends to more nearly equalize the voltage strains throughout the insulator.

As to a minor point, that of the factor of safety, Mr. Frazer thinks that it would be well if we could double the present factor of safety. I wonder if we had insulators which were twice as good as at present whether we would not shift up the 100,000 volts and make it 150,000 volts for the transmission line, and thus tend to retain the present factor of safety. That would be the temptation certainly.

Another question should be asked, and that is how we should measure this factor of safety. Mr. Jenks uses a factor of safety of five; he uses insulators tested at 125,000 volts on a circuit of 25,000 volts. If a 100,000 volt circuit is supplied with 200,000 volt insulator, then there is the same margin of 100,000 volts, although the factor of safety is only two. I think it probable that we may reduce our factor of safety as we go up higher in voltages. Possibly the 100,000-volt margin would be good in one case, and hardly enough in another, but I doubt whether it would be at all expedient to get a factor of safety of four or five by going to 400,000- or 500,000-volt insulators for use on 100,000-volt circuits.

I was interested in what Mr. Creighton said about the recording device for telling what lightning was doing. It certainly does give an excellent insight into the operation of the plant in connection with lightning disturbances to have such records, and it was my pleasure last summer to pass through Montana and spend a day or so at Mr. Gerry's plant, which is the Helena Power Transmission Company, the old Missouri River Power Company. At that plant there is a most excellent record of

lightning disturbances recorded putting paper slips in the lightning arrester gaps. They have a number of the multi-gap arresters, and papers are placed in the gaps next to the line and also in the various shunt circuits and ground circuits. These little telltale papers are taken out from time to time after storms. They give a record showing the results of the discharges in each wire of each line, at each end, and the character of that discharge is indicated by little holes or big ones. The condition is duly recorded on the little slips and the record is transferred to a larger sheet of paper so that one may see the whole record, showing the action on the different lines at each of its ends, and at the different points of each arrester. One can trace down how far the discharge went through the arrester, and where it passed off, and further, he can note the character of the discharge at each place.

I found there that the multi-gap arresters, with shunt resistances, had given such good service that the operating company considered this type as its standard. Electrolytic arresters were being tried but until they had demonstrated their value in service, the multigap arrester which had served efficiently so long were regarded as the standard arrester.

Percy H. Thomas: This is another one of our rare papers, wherein we have a perfectly definite, scientific record of the information obtained from commercial plants that will enable us to draw some conclusions which are almost mathematically definite.

This paper, it seems to me, taken in connection with the paper two or three years ago on the Taylors Falls lightning arrester experiments give us a pretty broad idea of what the transmission engineer has to meet in the protection of lines against lightning.

There are certain definite results and conclusions which we can draw from Mr. Nicholson's paper.

First, when insulators puncture, instead of flashing over, (then perhaps requiring an hour, or even half a day, to get the line into service again), this trouble can be presumably eliminated by the use of the rings proposed by Mr. Nicholson.

Second, where the insulators flash over and are broken by a power arc, the same remedy will apply.

Third, the attack of lightning on the transmission line, as distinguished from the station apparatus, is extremely local. Of this we have abundance of evidence now. One or two poles distance is too far removed from a ground to be at all sure of protecting an insulator.

Fourth, a resistance in the neutral point of the rising transformers may be a great help in maintaining service. I think Mr. Nicholson would probably agree to this statement. Thus grounding of one line is the cause of a much smaller arc than without this resistance, and furthermore the resistance enables the maintenance of voltage on the system, so that reverse-

current or overload relays can act while if a dead short-circuit should come on the system, the voltage being entirely removed from the relay, the relay cannot act.

Another point which has not been emphasized, but which is important, is the question of burning that is caused in the transmission line wire by an arc from the pin to the wire. Mr. Nicholson has given illustrated experimental data on this matter, and although I do not suppose it would be safe to draw conclusions from this case for all other cases, yet it gives a definite starting point. Mr. Nicholson fully realizes the fact that although the puncturing of insulators is overcome by the rings momentary interruption of the service is not preventive. Nevertheless the actual operation of the system has been very much benefited by the rings.

It is now very clearly established that insulators can be shattered by lightning alone without current from the generator, and without puncturing the insulator. The petticoats may be shattered without there being a direct puncture to the pin. This is a curious result and this is not the first time it has been brought forward. Presumably a remedy can be found for this condition; it would appear to be a mechanical strengthening, of the petticoats. The exact method will be for the insulator manufacturers to recommend. Ribs on the petticoat might be used, or a heavier petticoat.

Although we have not as yet gotten perfectly continuous service, we can still take a little comfort and not put so much stress on each occurrence of a momentary interruption. There are some classes of service where this is a serious matter, but as power systems go, a wink in the light, or the dropping off of the service for a moment or two, provided it does not occur too often, is not such an overwhelming handicap after all.

I notice Mr. Nicholson has made a study of the reports of various operating companies of the effect of ground wires overhead, and though I do not understand that his report is unfavorable to the ground wire broadly, yet, under the conditions which exist in his plant, he did not think it worth while to try them. I think we still ought to hope that the overhead ground wire will cause a very great decrease in the percentage of interruptions. The critical feature is not so much the mere putting up a ground wire in any convenient location on the pole or tower that may happen to fit a particular structure, but to so install ground wire and to so support and ground and locate it as to give the best opportunity for protecting the line in the light of the conditions to be met as we know them. One condition is the extreme tendency of an induced stroke to side flash when it strikes a ground wire. That means that between towers, on any long span, for instance, a stroke reaching the ground wire, would tend also to spill over on to the transmission wires. Thus, the middle of the span the ground wire should be more widely separated from the conductor than in the towers.

At the latter point where the ground connection is direct to earth, there is not the same necessity for using large spacing. The steel ground wire can usually be strung tighter than the copper wire, and there is often no reason why it should not be drawn above the transmission wire in the middle of the span, the point where the flash-over is most likely to occur.

Two ground wires would be better than one, especially where two transmission lines are on the same set of towers. I think we can safely assume that the attack of lightning is not directly from above; it tends to come from one side or the other and with a single centrally located ground wire may thus first reach the transmission conductor. The use of two ground wires will greatly reduce this tendency.

The cost of the ground wire is a serious item, but under favorable conditions we can erect transmission structures, in which the ground wire shall be an important element of the mechanical stability of the system. In that case, we could perhaps save its cost elsewhere in the system. I will ask Mr. Nicholson if he has any note of any cause of flash-over or puncturing of insulators, other than lightning. There was a time when we used to hear of "internal strains" and other similar troubles in the system, but in recent years we have not heard so much about that sort of trouble.

Mr. Fraser has brought out the fundamental necessity—more margin of safety. We used to have transformers go down frequently. The remedy has been to make better designs and use a larger margin of safety; the troubles with transformers have largely disappeared. If it were possible to do the same thing with high tension insulators, we should certainly be better off.

I feel pretty sure we would have progressed faster in our protection against lightning if that was the only problem we had to think of. The conditions are not at all favorable for the development of protective means. It is very rarely after the original design that in any particular practical case, there is a chance to act intelligently, and carefully and thoughtfully, to lay out a line for protection from lightning. Once in a while there is a company which is large enough to give opportunity for the engineer in charge to make a practical study of the lightning problem, as in the case of Mr. Nicholson's company, and to give an opportunity to try out the result of some method, and if that does not succeed, then to try something else. This is the method of investigation from which we are most likely to get results, as is indeed shown by the present instance.

J. A. Sanford, Jr.: Referring to the statement made by Mr. Scott that he understood that the insulators on Mr. Nicholson's line were rushed in on the line without complete test, using this fact as justification for the loss of insulators by puncture after installation, I think there is one statement in Mr. Nicholson's paper which partially covers this matter and which

is better justification for the above loss than the fact above referred to. The statement I refer to is as follows:

"The lesson of the year was not new but showed more forcibly than had been realized before that even if all insulators were capable of resisting puncture, they would continue to be shattered by a power arc following a flash over."

This statement would seem to show that although the manufacturers might have done everything in their power to furnish the best insulators that the art knew at that time, there still would have been a considerable amount of trouble from the breaking of insulators, due to lightning, which loss could only be overcome by the adoption of some protective device as is described in Mr. Nicholson's paper.

Referring to the question of factor of safety, I think that any of the manufacturers who would make a recommendation will recommend an insulator with a reasonable factor of safety, which, hitherto has been a rather flexible quantity, and that the engineer need not have any fear in allowing manufacturers to state what insulator is suitable for a given case, provided full information is furnished with the inquiry stating actual operating voltage, style of construction, and climatic conditions.

With reference to the size of insulator, Mr. Scott brought up the point that some of them were perhaps half the size of a barrel. The largest pin type insulator I know of was furnished to the Edison Company of Los Angeles, being 18 in. in diameter, about 14½ in. high, and this insulator weighed net 43 lb. The largest suspension type units used up to the present time have been made up of two pieces of porcelain, the largest being 14½ in. in diameter and the distance between the point of suspension and the lower petticoat of the insulator being about 10 in.

E. B. Merriam: There are a few points which I wish to mention based on observation of the destructive effects of high-power electric arcs on insulators. A power arc provides a path of low resistance, which on a large system permits a tremendous amount of current to flow, at the same time preventing an abnormal rise in the line voltage, the circuit being opened by protective apparatus. The resistance of these arcs is quite low and might be compared to an equivalent length of No. 0000 copper wire stretched around the insulator. It is the low resistance of this arc which holds the line voltage down until such a time as the circuit can be opened by the line oil circuit-breakers. The size of the arc is not always a measure of its destructiveness as the reflection of the vapors may give the appearance of an arc of great magnitude. A small arc will sometimes cause more trouble than a large one if it is allowed to hold for any appreciable length of time. The time element, therefore, figures quite largely in the amount of damage and burning to the insulator.

The pin insulator, having a petticoat around the insulator pin, is particularly susceptible to the ill effects of heavy power arcs, hence the necessity of protective rings. These petticoats

may be broken off one after another on account of the arc "pocketing" and hanging close to the porcelain. The suspension type of insulator, owing to its peculiar construction, has an inherent protection as the arc has a tendency to flare away and extinguish itself. Tests on the suspension type of insulator indicate that protective rings are not necessary. In making tests of this nature it is highly essential that they be made out of doors under operating conditions, as the wind causes the arc to "wander," and the pressure and condition of the atmosphere also have marked effects on the arc, making a laboratory test misleading.

Harris J. Ryan: By practice and investigation that are record breaking for extent of facilities employed and the experience encountered, Mr. Nicholson has advanced greatly our understanding of the related causes that bring about injury and failure of high-tension transmission line insulators. To limit the damaging effects of these causes, he devised and applied to the insulators rings that accomplish their purpose in two fundamental ways:

1. The power arcs that follow a "spill-over" are held free of the insulators.

2. The stray static field set up by the arcing ring is made to crowd the field set up by the skirts of the insulator. For the upright insulator this is so managed that the capacity of the shell next to the pin is considerably diminished. The charge entering such shell from the top of the pin is lessened and the electric stress or pressure gradient there applied is correspondingly lowered. The net result is a more uniform distribution of potential gradient among the several shells along the route of maximum electric strain.

The paper brings up again the principle that pressures are developed on transmission lines at times, that are too high to be withstood by any practical system of insulation and that their effects are localized to such a degree that they cannot be cared for by arresters distributed to a reasonable extent. This and the principle that governs the use of arcing rings have been realized by the author of this paper in a new design of an upright insulator in which enough well-disposed porcelain is used to set the puncture pressure safely above the arc-over pressure. It has been shown that this insulator in combination with arcing rings, has made an important advance in transmission practice.

Mr. Nicholson made tests to determine the destructive effects of power arcs upon transmission lines with and without the use of arcing rings. He found that the arcing rings exercised no material influence in this matter, *i.e.*, they neither increased nor decreased the liability to such damage. In the early part of the paper the author tells us that, "The gaps perfectly protected the insulators containing them". Did they also protect the aluminum cables at corresponding points from damage by power arcs? When a light wind is running, approximately

parallel to the line, and a heavy power arc is thereby drawn away from the arcing ring and over the aluminum transmission cable, could not the damage to such cable be prevented by the use of a suitable aluminum guard covering the cable a few feet on either side of the insulator? If required, the power arc at the remote end of such cable guard could be stopped by a barrier of the same metal in the form of a solid disk or an extension piece deflected at right angles to the cable; for the upright insulator, such barrier-piece should be directed downward; for the suspension-type insulator it should be directed upward. Does Mr. Nicholson's experience lead him to consider that guards of this character for protecting aluminum cable are worth what they cost to apply and to maintain? Does his experience lead him to conclude that the transmission cable mounted from suspension-type insulators equipped with arcing rings would or would not be comparatively free from damage by power arcs because of its under-hung position?

Applied to the suspension-type insulator, the arcing rings, by crowding the stray static field about the lower unit, will distribute more evenly the total electric strain among the different units; this should result ultimately in a real advance in the practice that employs this type of insulator.

Irving E. Brooke: The proper protection of high tension transmission lines from injury by lightning or other electrostatic stresses is one of the most important as well as the most difficult problems encountered in the design and construction of transmission lines. The author states that the test on the insulators in question consisted of subjecting each part of the insulator to 75,000 volts for three minutes, but further states that the complete insulator was not tested after assembling. The writer does not understand why the complete insulator was not tested after assembling. In tests of this nature it is not an extreme case when 10 per cent of the tested insulators will break down when subjected to approximately twice the line voltage for which they are intended.

The fact that so many of the insulators fail and puncture is probably due to the design of the insulator, as the potential gradient is such as to subject the top piece or the pin piece of the insulator to a stress greatly in excess of that for which they were designed. This matter of potential gradient for insulators is one that should be thoroughly investigated.

If insulators are made in more than one piece, and although each piece may stand up under the specified test when the several parts of the insulator are cemented together, the distribution of the electrical stress is not the same as if the insulator was one homogeneous mass. When the insulator is made in one piece it is probable that a uniform potential gradient will be secured. As Portland cement is much inferior to porcelain, at the point of contact of the two materials we may have a very abrupt change in the potential gradient or perhaps a re-distribu-

tion of the electrical stresses. It has been demonstrated that one piece insulators seldom fail by puncture from operating voltage, but multi-part insulators fail by puncturing one section at a time, which is undoubtedly due to unequal potential distribution.

The subsequent design of the shorter insulator shows a much better type as regards mechanical strength and also an insulator that will withstand approximately the same voltage test.

It is interesting to note that the lightning troubles have been confined entirely to lines themselves and that no trouble has been experienced in stations or substations that could be charged directly to this source. This may be due in a large measure at least to the fact that the steel tower construction with proper station protection provides an easier and more direct path for the relief of high potential charges induced by lightning than that through the station or substation apparatus. The fact that a number of insulators have been broken by a direct stroke may be on account of the so-called lightning-rod effect of the steel tower construction. An insulator could be designed which would flash over before it punctured, but it is hard to foresee which would give better results unless some protection as described by the author were provided to protect the insulator from the power arc after a flash over occurred. The result showing the number of insulators broken on the top wire should be a good guide in the placing of a ground wire on a transmission line.

The question of putting resistances in the neutral connection of the substation transformers is one that is open to argument on account of the possibility of increasing the potential on the line by limiting the current flow to ground.

It has been shown in many instances that a lightning discharge apparently will not always follow the path of lowest resistance. In some instances it has been known to jump several feet at the turn of the wire rather than follow the same wire only a few feet farther, but in a line at an angle to a direct path, to the ground. This may to a certain extent explain the reason why the station and substation apparatus experienced no trouble from lightning discharge. It should also be a good argument for the provision of a ground wire on the transmission line.

In placing the rings around the insulator the author has shortened the air gap, or distance to ground, and while the ground potential is still carried well up inside the insulator it is hard to make the power arc hold from the pin to the conductor.

The log of operation shows some very interesting results. The fact that the circuit breakers were tripped out so many times on the re-insulated line is probably due to the fact that the placing of the arc rings lessened the line insulation and that it brought the ground potential up nearer the conductor.

James Lyman: The author has shown great ingenuity in successfully overcoming the serious effects of lightning discharges over unprotected transmission lines. The method ap-

plied will undoubtedly prove of great value to similar situations where the arrangement of insulators on the pole or tower structure does not permit of an overhead grounded cable located well above the transmission conductors.

The value of such a grounded cable in absorbing the high tension charges from clouds and discharges from clouds to ground has been clearly demonstrated by actual experience on many transmission lines. The effectiveness depends, of course, on its being well grounded at frequent intervals, say at every pole or tower structure, and it should be carried well above the line it is to protect. The potential of the earth is thus brought to the level of the grounded cable, and the transmission line is, therefore, removed from the zone of lightning discharges.

If the overhead cable is badly grounded, as, for example, to dry earth or rock, it, of course, offers less protection. In general it is possible to obtain good grounds at small expense. Where good grounds cannot be obtained, as occasionally happens in crossing mountain ranges and rocky country, the author's protecting rings can well be used in addition to the overhead grounded cable.

I believe the overhead cable, grounded as well as conditions will permit, will always offer a very material protection.

Mr. J. B. Foote, engineer for the Grand Rapids-Muskegon Power Company, adopted an original method of protecting the fifty miles of 110,000-volt transmission line, from Croton Dam to Grand Rapids, without an overhead grounded cable, which apparently is entirely effective, for during the year of 1909, not one case of trouble from lightning occurred, although on an older 60,000-volt wooden transmission line a number of interruptions from lightning occurred.

Steel towers are used with an angle iron extension six or eight feet above the upper transmission line acting as a lightning rod. To obtain a good ground the angle iron base extends two feet below the concrete foundation, or a total of six or seven feet into the ground at each corner. The pole line passes through an open farming country where the soil is deep and moist. The line is thus protected by a lightning arrester at each tower or at intervals of from 400 to 500 ft. The suspension type of insulator lends itself well to this construction and wherever steel towers and suspension insulators are used this arrangement might successfully be adopted.

Max H. Collbohm: The method described in Mr. Nicholson's paper is a means to save the insulators from destruction by electrical forces. It does not offer any direct protection to the transmission wires or the station itself. The usefulness of this method is apparent by the fact that if lightning surges are set up either directly or induced in the power wires with a potential high enough to cause arcing over the insulators then a shut-down of the line may result (particularly in a grounded star connected system) without destruction of insulators, thus per-

mitting service to be resumed immediately afterwards, while if this method was not employed the insulators may be destroyed, resulting in a continued interruption of service until the damaged insulators are located and replaced.

The arrangement of the protection rings at about the elevation of the lower petticoat, with a corresponding reduction of sparking distance between conductor and ground, would seem to make it permissible to materially reduce the length of the pin as used at the present thereby increasing its strength.

There is one point in Mr. Nicholson's paper to which I would like to take exception, *viz.*, the statement that it has been found useless to install guard wires over the transmission lines for lightning protection. Although it is true that guard wires do not afford complete protection to the line, they give however at least a reasonable degree of protection if properly installed, *i.e.*, high above the power wires and grounded at every tower. They should furthermore consist of durable non-magnetic material (at least on the outer rim of the conductor) such as found in copper-clad steel wire, and should be at least as strong mechanically as the power wires themselves.

The writer believes that the past failures of guard wires to protect the line are in a great measure due to infrequent grounding and the use of improper material, such as steel. The writer has made some preliminary experiments with high frequency currents which have proved the superiority of copper, or copper-clad steel, over iron as material for grounded guard wires.

G. Semenza: Mr. Nicholson's paper is interesting from two points of view; the statistical one, on one side, as it describes a number of very severe troubles, and studies them in a coordinate way; and the technical one, on the other side, as it proposes a new protecting device which must be considered with the closest interest. Such a device appears to be theoretically effective, and the figures deduced by experience seem to show that it is so in fact.

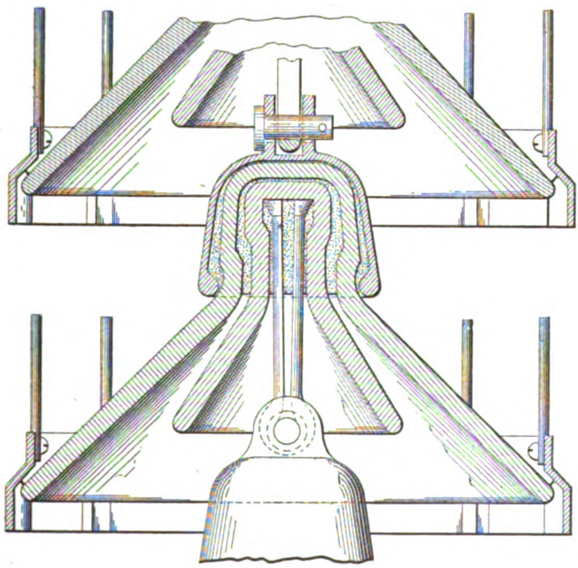
A closer consideration of the figures given, however, discloses some objections which make it desirable to obtain more complete data. First of all, the number of insulators punctured on the old line, both in operation and in the testing room, is considerably in excess of anything heretofore known. The thickness of the porcelain that is punctured in such an insulator ought to stand the testing voltage quite easily, so that, to the writer, the large number of failures would be attributed to imperfect baking of the porcelain.

As to the comparison between the old and the re-insulated line, it is to be noted that while the old line has been left as it was, on the new line 39 per cent of the insulators on the two lower wires, and all of those on the top one, have been replaced with a new and more modern type of insulator. For this reason it is not possible to determine how much of the improvement is due to the re-insulation of the new line.

In a general way it is not apparent how the rings can prevent the puncturing of the insulators. The effect of the rings may be to cause a flash-over to occur more easily than a puncture: such a result may be met by a better proportioning of the parts of the insulators. The protection of the petticoats in case of flash-over must be, on other hand, very effective, as the rings tend to draw the arc out of reach of the porcelain.

I would ask if, in consideration of the slight effects caused by arcs on the cables, it would not be easy to simplify the device by using a single bent wire projecting from the pin and turning upwards to the cable?

J. D. E. Duncan: The paper presented by Mr. Nicholson shows how closely different persons coincide in some cases in the ex-



pedients they adopt for the same purpose. The writer has previously developed quite similar arcing rings in connection with high tension insulators devised for use on the Stanislaus installation. One form of these arcing rings shown on a suspension type of insulator is indicated in the diagram shown herewith.

These arcing rings prevent excessive electrical pressure being exerted on any of the insulator elements; where, for example, a portion of the shells or elements has become temporarily ineffective through dust or moisture or where excessive pressure is exerted as in the case of lightning. By surrounding the entire insulator with an arcing ring any arc formed along the surface of the insulator inevitably moves out to the ring through heat and wind action and then the ring itself carries the discharge,

the arc then being so far removed from the insulator as not to be dangerous to the porcelain. The rings are arranged so as to have an air space and air circulation around the outer edge of the petticoats so that any heat developed in the rings themselves will not be harmful and as the writer worked up this protective device the rings were mounted on various parts of the insulator structure, such as the petticoats, heads, and other parts.

In theory, the ring is practically a metallic conductor cage arranged around the insulator element and sufficiently removed from it to prevent any contact between the arc formed and the insulator itself, and the arcing distance from the arcing ring to its coöperating arcing points is so arranged as to make this relief path operative before dangerous or puncture voltage is approached. These arcing rings proved entirely effective when tested under conditions approaching those of commercial operation, and arcs generated by a transfor merhaving several hundred kilowatts capacity were disposed of without injury to the insulator in any case.

It may be of interest to briefly refer to the fact that these arcing rings and insulators were devised in connection with the high tension Stanislaus transmission line, which was designed, and the insulators developed, before lines at 100,000 volts were considered practical and before any lines had been put in commercial operation at more than the nominal 60,000 volts potential. A suspension type of insulator was finally adopted as being by far the most suitable for these conditions and because it was especially adapted for such increase of voltage as might from time to time prove necessary. This form of suspension insulator having a plurality of nested domes and attached petticoats has proved highly reliable under commercial conditions, as is evidenced by the operation of this Stanislaus transmission line for over ten months without interruption.

L. C. Nicholson: Replying to Mr. Catching's question concerning voltage disturbances accompanying discharges to the rings, there is practically none when one phase discharges. This is on account of a high resistance neutral which limits the current flow to about 30 amperes. Voltage disturbances accompanying simultaneous discharges on two or more phases are very great; in fact, under such short-circuit conditions there is practically no voltage anywhere.

Mr. Creighton asks for concrete cases of lightning stroke at various distances from the lines, and the corresponding effects upon the line. I regret that we have no very considerable data on this point. I have ventured to make a statement which indicates how we feel about it—less than 500 feet away is very dangerous, more than 3000 feet away fairly safe. Various observations made from time to time seem to indicate these general limits. Causes other than lightning which may produce flash-overs are few. Opening a long section of unloaded line by means of open-air disconnecting switches sometimes sets up surges

which cause flash-overs. The accidental grounding of one phase as by a tree branch or other object, lightning arrester discharge, etc., may cause flash-overs to occur on another phase at another point on the line, due to the sudden re-arrangement of the electrostatic conditions of the system. Surges produced in this manner frequently reach very high values.

I agree with Mr. Thomas that insulators may be shattered completely by pure lightning effects, unaccompanied by puncture or power. I think he is also correct in that the attack of lightning is frequently from the side instead of from above. I have a case in mind where two east and west parallel lines twenty six feet apart, insulated in the same manner suffered very unequally from lightning, the south line sustaining practically the entire damage, the north line being nearly immune. In this case the storms approached from the southwest.

As to the length of time necessary to injure an insulator by a large arc, a perceptible time is required, though very slight, perhaps about one quarter second, with a 10,000-kw. arc.

Mr. Ryan suggests the use of a metal disc on the cable to prevent the arc travelling out beyond the unprotected portion of the cable. We have experimented with this and other equivalent arrangements, but have not found anything that will deter the arc. In fact any obstacle on the cable appears to be objectionable since it furnishes a shielded zone in the lee of which the arc may rest and accomplish considerable burning.

Protection by a sleeve or serving of small wire would be entirely effective provided such protection extended far enough along the cable. However, such protection would necessarily extend, say, 50 feet each way from the insulator, since frequently arcs travel this distance along the wire. Two cases are on record where the arc extended from the lower ring to a point on the cable 250 feet from the insulator. If the passage of the arc along the cable is unobstructed, the burning is not serious. Twelve cases occurred in the season of 1909 in which the cables were blistered for from 5 to 50 feet. No cable was burned seriously enough to warrant repairing. Our conclusion is that the cable should be bare, so as to allow the arc to travel readily along it, which action forestalls serious burning at any one point.

In the case of suspension insulators, protected by rings, burning of the cable cannot occur since it is impossible for the arc to come in contact with it.

Something has been said about automatically sectionalizing parallel lines in case of a ground on short-circuit on one of them. We have found it entirely feasible to cut out a grounded line automatically by the use of a specially constructed relay. However, short-circuit, low-voltage conditions are very hard to treat, and while some progress has been made with automatic devices they are at present considered far from satisfactory.

As to the efficiency of an overhead ground wire in protecting

against lightning, several gentlemen seem to construe my remarks on this subject as being entirely unfavorable to the use of a ground wire. Such was not intended, and our reasons for not installing such protection are as stated, *viz.*, the heavy expense incident to properly installing it on structures such as ours, already built, together with the extra load such wire or wires placed well up above the line would impose; and, as a result of an extensive canvass we concluded that the benefits to be derived from such protection were far from ideal and did not warrant the expense. We were looking for something better and less expensive than the overhead ground wire. It may be that it takes overhead ground wires, arcing rings, suspension insulators, and more, to eliminate all lightning trouble.

Mr. Brooke concludes from the log that the reason the reinsulated line tripped out so many times is due to the fact that the placing of the arcing rings lessened the line insulation and brought ground potential up nearer the conductor. We interpret the operating results differently. For example, considering the 38 cases of flashover found upon inspecting the reinsulated line, tabulated on page 261, 17 were complete flashovers to the pin, and consequently the entire insulation of the line was developed. Moreover there were two-thirds as many trip-outs on the old line as on the reinsulated line, and in addition there were 15 instances of disablement on the old line. Assuming approximately the same amount of lightning on the two lines, the reinsulated line shows 20 trip-outs against 27 on the old line. I call attention here to an observation omitted in the paper, *viz*, in only three cases of the thirty-eight inspected was the initial discharge vertically downward from the cable to the ring. In thirty-five cases the discharge emanated from the tie wire in the neck of the insulator, either to the pin or to the ring. Our conclusion is that under average conditions of moisture on the insulator surface during storms the rings are not close enough to reduce the degree of line insulation. It is entirely feasible to lower the ring so as to develop the full dry flashover value of the insulator, in which location the ring is equally effective in taking the power arc off the pin.

Mr. Semenza's opinion that insulators should be designed so as to flash-over before they are punctured is entirely concurred in. This is what we have attempted to get in the new style four-part insulator. On the other hand, given any insulator, it is possible by a ring to reduce its dry flashover value to a point comparable to its puncture strength, and at the same time keep the wet flashover value normal. There is, moreover, no great objection from an operating standpoint to doing this. This is what we have done with the old type insulator.

As to replacing the ring by a gap from the cable to a single bent wire, leading upward from the base of the pin, this would be equally as effective as a ring, but for only one condition of wind direction. An insulator flashes over on its wettest side,

which is the windward side, in a lightning and rain storm. Were the proposed gap set at a value less than wet flashover so as to attract all flashovers (wet and dry) two objections arise; first, the degree of line insulation is reduced and, second, under certain wind directions the arc would attack the pin and destroy the insulator. A continuous metal ring enables the arc to shift readily around the insulator and to accommodate itself to all wind directions, and always to the leeward of the insulator. A horizontal gap at the top of the insulator, if set below wet flashover value, will prevent injury to insulators by power arcs, but such gaps are more difficult to construct and if set close enough to prevent insulator "spill-overs" are a menace to operation. Our experience with gaps of this nature indicates that it is impossible to adjust and to keep in adjustment a large number of them.

I wish here to add some data which shows the effect of the lower ring to reduce the puncturing tendency of the three-part insulators. We recently had occasion to test 800 of these insulators, first with the ring in place and then with the ring removed, the voltage in each case being sufficient to cause flashovers, *viz.*, 160,000 with the ring and 195,000 without the ring.

Failures with ring.......................... 3 per cent
Failures without ring........................22 per cent

Of the 3 per cent failures with ring, only 1.25 per cent was due to failure of the pin-piece, whereas of the 22 per cent failures without the ring, 17 per cent was due to the failure of the pin piece.

Mr. Duncan proposes the use of metallic rings supported on the insulator parts. I understand from his remarks that this device was developed experimentally, with small amounts of power. Several years ago an arrangement such as this was proposed for our insulators, but subsequent tests showed it to be entirely without effect when large amounts of power, say, 10,000 kw. and over, are put into the arc. Since the damage to the insulator is caused by the lower terminal of the arc running up the pin, the only cure is to take the arc off the pin automatically and immediately after its formation. So long as this is not accomplished, the insulator will be destroyed. Experiments show that the attenuated portion of a large power arc approximately eight inches and more away from its termini is not destructive to porcelain even though in continuous actual contact therewith. For this reason little good is accomplished by "short-circuiting" the arc as it passes the edge of the insulator skirts, while allowing its terminal to remain on the pin of an upright insulator or the metallic links of a suspension insulator. Furthermore a very slight breeze causes the body of the arc to flare clear of the insulator skirts, even with conducting bands about them, which action prevents the metal bands from performing any function. There is no reason why the arrangement mentioned will not limit the puncture stresses to any desired amount.

The operating results given in the paper would hardly be complete without referring to our Waterloo of 1910, when two insulators on the reinsulated line were exploded by what appears to have been a direct stroke of lightning. A number of other insulators on adjacent structures flashed over, but were uninjured. This incident shows that there is a degree of lightning which is fatal to protected insulators, but from past experience we know that such occurrences are very rare.

During another storm of 1910, the telephone line 100 feet from the power line was struck and several poles splintered. Flash-overs occurred at that point on the power line, but no insulators were damaged. This result indicates that the line is practically proof against breakage by anything less than a direct stroke.

The general bearing of this situation it seems to me is this—we have transmission lines which will operate practically without extended interruption, but with a number of momentary interruptions during the season, momentary short circuits, I should say, which are sufficient to throw out of step the present type of synchronous receiving apparatus on the system. I believe the results point to the necessity for the design and the use of synchronous apparatus, which will suffer heavier disturbances of voltage than the present type can withstand.

A paper presented at the Toronto Section of the American Institute of Electrical Engineers, Toronto, Can., November 19, 1909.

TUNGSTEN LAMPS

BY G. S. MERRILL

The perfection of the tungsten incandescent lamp as a highly efficient means of converting electrical energy into light has made it a subject of great commercial interest. The tungsten lamp has reached in a comparatively short time a most enviable position in the field of artificial illuminants. It has been developed for multiple use on commercial lighting circuits up to 260 volts, for series street lighting, for low voltage decorative, display and train lighting, and for many other purposes. Its commercial success in all these various applications bears witness to its merit as a convenient and efficient source of illumination and its production and characteristics are consequently worthy of consideration from an engineering standpoint.

A discussion of the historical side of the high-efficiency lamp development is very interesting, but as this can be found fully covered in current technical papers it perhaps is not necessary to review the line of experimental and research work which produced the modern high efficiency lamp. Neither is it necessary to describe the several different processes by which various experimenters have produced tungsten filament, since these too can be found thoroughly covered in connection with the historical development.

The process most widely used in the United States to-day is one which starts with the purest tungstic acid or anhydride obtainable as its basic material. Tungstic acid is obtained commercially from the ores wolfram, a ferrous manganous tungstate, scheelite, a calcium tungstate, and hubnerite, an oxide of tungsten and manganese. The tungstic acid as received by the lamp manufacturer is in the form of a heavy yellow colored powder

and notwithstanding its purity has to undergo a most thorough further purification and special treatment in order to reduce it to a fine yellowish powder which possesses a slight porosity. This peculiar physical condition is necessary for the successful reduction of the oxide, which can be accomplished in several different ways perhaps most easily by heating to redness in a current of hydrogen. Tungsten as used in steel making is reduced from the oxide by heating with carbon in crucibles, but the resulting metal is not pure enough for the manufacture of tungsten filaments, which are seriously affected by the presence of combined carbon. It is also possible to reduce the oxide by heating with metallic zinc, the two substances being in a finely divided state and thoroughly mixed before heating.

The tungsten as obtained from the process of reduction employed in lamp manufacture retains the physical characteristics of the oxide inasmuch as it is finely divided and slightly spongy. The metal in a mass has a bright metallic luster resembling platinum. In the powdered state it is grayish black or dead black depending upon the fineness of the powder and the temperature of reduction.

After obtaining this very pure metallic tungsten, the next operation is to mix it with a binding material in order to form a plastic mass that may be squirted into the fine threadlike filaments. Various substances can be used for this purpose but some compound of carbon, oxygen, and hydrogen such as starch, sugar, camphor, etc., is usually employed. The metallic powder when mixed with such a binding material has somewhat the consistency and appearance of black putty. It is absolutely smooth and uniform and it is impossible to detect the slightest grain. This paste, as it is called, is placed in a small steel cylinder and forced, by a pressure of about 32,000 lb. per sq. in., through a small diamond die.

The die used in squirting tungsten filament consists of a suitably mounted diamond of from one-half to one carat in weight through which a very minute hole has been drilled. In the smaller dies used to-day this hole is only about 0.0014 in. in diameter which is smaller than an ordinary hair. The hole is drilled in the diamond with a steel needle, ground down so fine that it is as flexible as a hair and, as can be imagined, the drilling requires considerable time and patience. The stone when drilled is mounted in a steel casting in order to hold it against the enormous pressure used in squirting the filament.

Under such pressure the abrasion of the die even by the smooth tungsten paste is very rapid. This abrasion is a serious matter as the diameter of the hole, and consequently that of the filament squirted, constantly increases. Moreover the abrasion is not uniform, so that the hole enlarges more rapidly in the direction of one diameter than of the other, assuming when worn an elliptical shape. After enough filament for about 1,500 lamps has been squirted, it is necessary to have the die rebored, an operation which costs almost as much as the original die. A die cannot be rebored more than twice before it develops cracks or fissures which cause it to break. The next hardest material, sapphire, has been experimented with as a material for these dies but it is found that such a die is very liable to split and that it will hardly make 100 lamps before it needs re-drilling.

The filament, after squirting, has been likened in character to a filament of putty, that is, while holding its form well and being flexible to some extent, it is liable to break if bent sharply. The filament as squirted is looped back and forth on cards and after being allowed to dry is cut to form a number of single loops much as they are seen in the finished lamp.

The next operation is to heat the filaments in an inert gas, or in one chosen to act upon the particular binding material employed, until they reach a red heat which removes any moisture and lighter hydrocarbons that may be present. Each filament is then mounted in current conducting clips so that it may be heated by passing an electric current through it. During this final heating or forming, as it is termed, the filament is supported vertically with the loop downward. A very small weight (a few milligrams) is hung in the loop to prevent the filament from being distorted in shape during the heating which is usually performed in either an inert gas or in a very good vacuum, the gas, if used, being again dependent to some extent on the binding material employed. The temperature of the filament is raised gradually, allowing time for the proper reactions and physical changes to take place. During the heating, the energy input into the filament rises to about fifteen times that finally required in the lamp, and while some heat is carried away by the forming gas the temperature is undoubtedly much higher than that reached in subsequent operation.

Every trace of binding material is driven out, and the filament when finally brought to a sufficiently high temperature undergoes

a sudden and marked contraction in diameter and length as the small semi-molten particles become soft enough to merge into one perfectly homogenious mass. A piece of such filament under a microscope resembles a drawn wire and while the surface is not perfectly smooth there is no indication of a granular structure.

At a dull red heat any good tungsten filament is flexible enough to be bent as desired but when cold is somewhat fragile. For this reason it is a good thing if possible to light tungsten lamps while cleaning them, the chance of mechanical breakage being then minimized. Lamp packages have been devised that eliminate a considerable amount of breakage that would result from rough handling so that, if the lamps are left in the original cartons until placed in service, and handled with even ordinary care, the question of breakage will be found to be of little importance.

In order to secure a uniform quality of filament, which is absolutely necessary for good lamp making, every step of the entire process of production even to the smallest detail must be carried through with exactness. For example the rate at which the temperature of the filament is raised during the forming process has a most important effect on the final filament structure, and must be carried out with extreme care in order to assure a perfectly uniform run of filament.

After forming, the filaments are mounted upon the familiar glass supporting rod as seen in the finished lamp, and the joint between each leg and the supporting and conducting terminal made by electrically welding the filament to the support. This makes a very perfect joint both electrically and mechanically.

The material used for the hooks and supporting wires affects the performance of the lamp to a considerable extent. Soft copper is used extensively for such supports, also, to a somewhat lesser extent, molybdenum, tungsten, tantalum, thoria, carbon, platinum, iridium, or other refractory materials. Soft copper does not alloy with pure tungsten and moreover occludes but very little gas so that it makes a very satisfactory form of supporting hook.

The process of producing a high vacuum within the bulb of a tungsten lamp is a great deal more laborious than in case of the carbon lamp. It is necessary, in order to produce a good lamp, and this applies to carbon and other types as well, to remove every trace of gas, not only that actually free at the time of pumping but that which may later be liberated from anything

within the finished bulb. A good lamp vacuum is only possible through the use of very perfect exhausting machinery and through subjecting the entire lamp, filament, glass, and other parts to a proper heat treatment, during the pumping process. The heat treatment tends to drive from the glass walls and other surfaces exposed within the bulb the particles of air which cling to them in a thin film with surprising persistence. A glass bulb pumped while cold will apparently reach a high degree of exhaustion at the end of the pumping process, but, if left standing for some time, will be found to possess a very poor vacuum as judged from that required to insure good lamp performance. This is due to the gradual liberation of particles of air which, during the pumping, cling to the interior surfaces. The filament s heated intensely by passing an electric current through it while on the pump in order to drive from it and from the supporting wires, which are heated by the incandescences of the filament, any occluded gas which may later be freed from these parts and thus spoil to a certain extent the perfect vacuum required for successful operation. During the pumping process the filament temperature must be regulated with great care, the temperature being raised gradually as the bulb becomes evacuated. If, for example, the temperature should be raised, too quickly, a thin film of oxide will form on the surface of the filament which, although entirely removed by a further rise in temperature and higher degree of exhaustion, will have been found to have caused a slight change in the character of the surface of the filament, altering thereby its emissivity and radiating properties and injuring its subsequent life performance.

After pumping, the lamps are given an exhaust inspection and aging by burning at a certain percentage over voltage. If during this inspection any lamp develops or shows a bluish color or haziness within the bulb it is an indication of imperfect vacuum and the lamp is rejected. The period of burning and per cent over voltage depends somewhat on the size of the lamp, but in every case has been chosen so that if a lamp is at all likely to develop a poor vacuum it will be disclosed on this inspection.

The glass work required in making the tungsten lamp is, with the exception of the center glass stem, practically the same as in the other types of incandescent lamps.

I have now covered in a general way the process of producing the tungsten lamps, and have I hope given some slight idea as to the care required in such production. In order to show

the performance of the lamps in subsequent service, I have averaged the candle-power life curves of 50 40-watt tungsten lamps which were burned on life test at constant voltage cor-

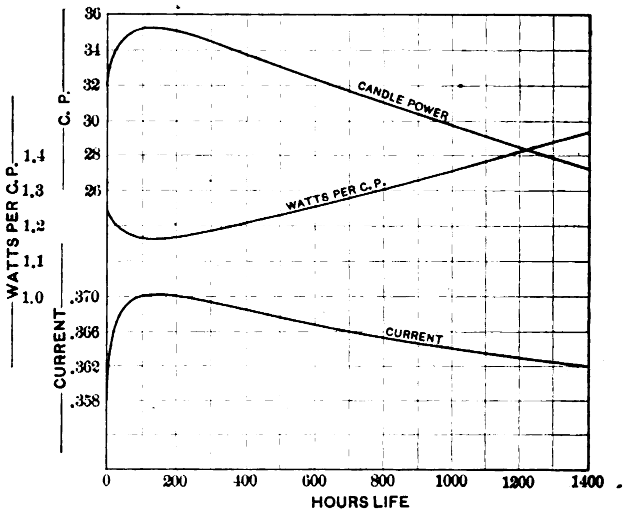


FIG. 1.—Characteristic performance of 40-watt tungsten lamps

responding to an initial consumption of 1.25 watts per mean horizontal candle-power. The curves in Fig. 1 show the change in candle-power, current and efficiency during the period of test, which was stopped at about 1,400 hours. In order to show the

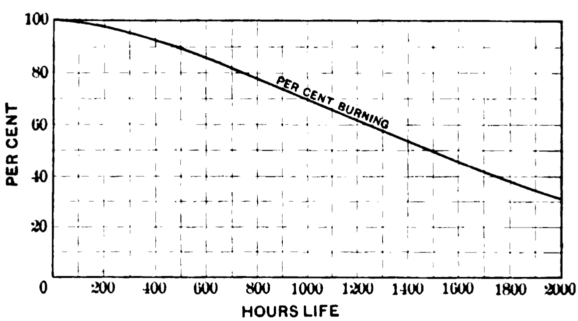


FIG. 2.—Mortality curve of 40-watt tungsten lamps

life performance, a curve is given showing the per cent of lamps which were burning at the end of various periods of time. These curves, Fig. 2, are the average obtained from 80 40-watt tungsten lamps burned under same conditions as the previous

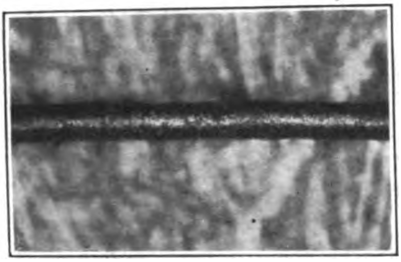


FIG. 3.—Unmounted tungsten filament

FIG. 4.—25-watt tungsten—400 hr.—alternating current

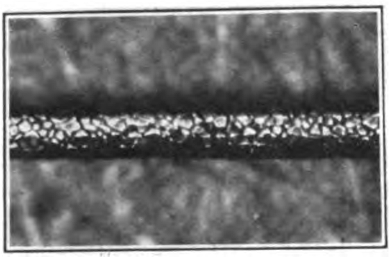


FIG. 5.—40-watt tungsten—180 hr.—alternating current

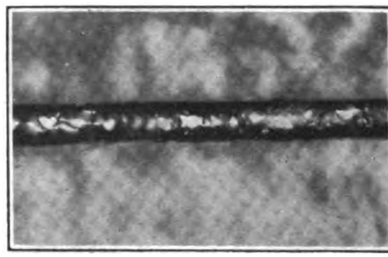


FIG. 6.—25-watt tungsten—1400 hr.—alternating current

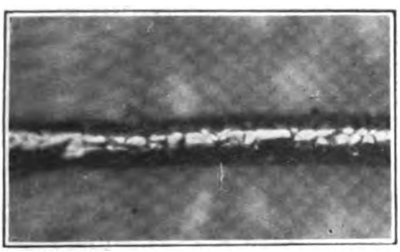


FIG. 7.—40-watt tungsten—898 hr—alternating current

FIG. 8.—40-watt tungsten 2190 hr.—alternating current

FIG. 9.—40-watt tungsten—300 hr.—direct current.

FIG. 10.—40-watt tungsten—3000 hr.—direct current

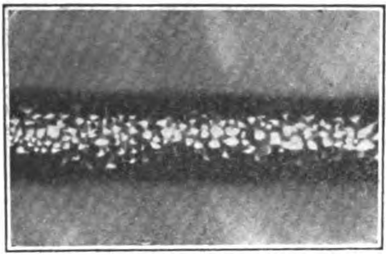


FIG. 11.—100-watt tungsten—1400 hr.—alternating current

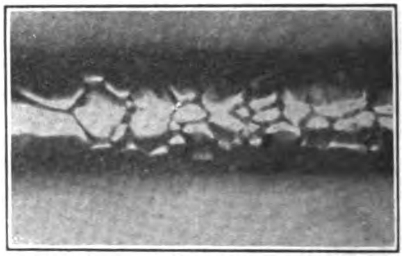


FIG. 12.—250-watt tungsten—2000 hr.—alternating current

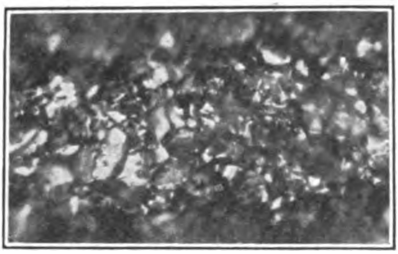


FIG. 13.—Tungsten—Street series 2000 hr.

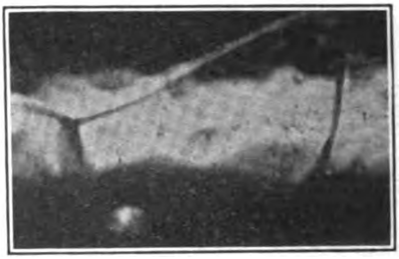


FIG. 14.—Tungsten—street series —3349 hr.

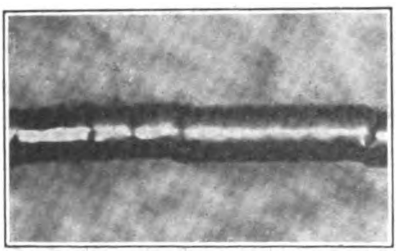


FIG. 15.—80-watt tantalum—800 hr.—alternating current

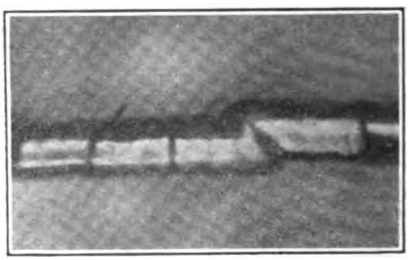


FIG. 16.—80-watt tantalum—400 hr.—alternating current

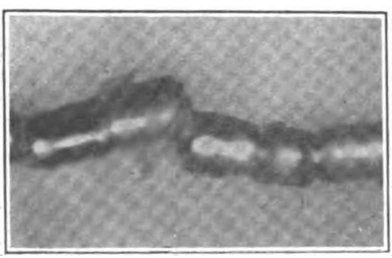


FIG. 17.—40-watt tantalum—800 hr.—alternating current

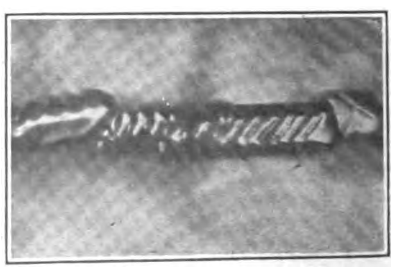


FIG. 18.—80-watt tantalum—948 hr.—alternating current

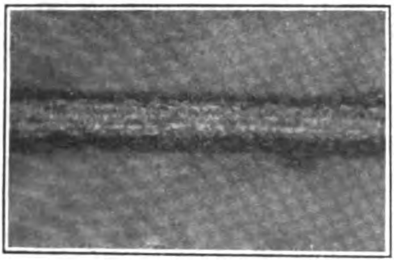


Fig. 19.—80-watt tantalum—60 hr.—direct current

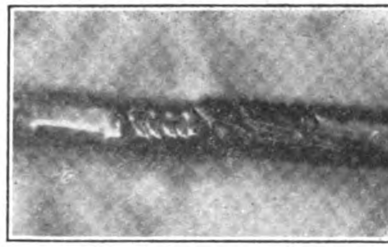


Fig. 20.—80-watt tantalum—455 hr.—direct current

Fig. 21.—80-watt tantalum—1058 hr.—direct current

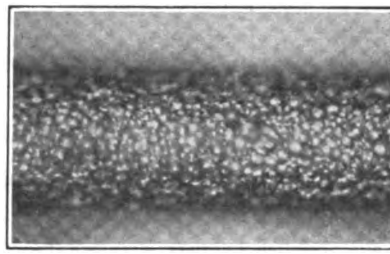


Fig. 22.—Gem—841 hr.

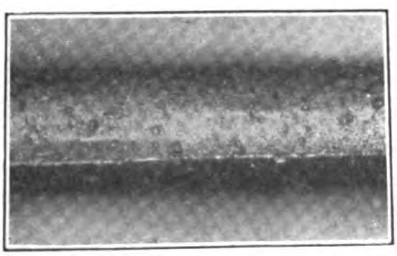


Fig. 23.—Carbon—508 hr.

test *i.e.*, at 1.25 watts per c.p. About one half of the lamps were burned in a horizontal position and the others in a vertical position, tip downward. These tests were stopped at the end of 2,000 hours.

The change in appearance of the filament during life is rather interesting, and some illustrations showing filaments taken from lamps which had burned for various lengths of time are shown in Figs. 3 to 23. For comparison, a few tantalum filaments as well as filaments from a gem and from a carbon lamp are shown.

The relation between candle-power watts, amperes, ohms, volts and watts per candle is shown by the characteristic curves of tungsten, Fig. 24.

For the normal range of operation these curves can be expressed in the form of parabolic equations a few of which are as follows:

Let C = candle-power.
e = efficiency in watts per candle.
V = voltage.
W = total watts.

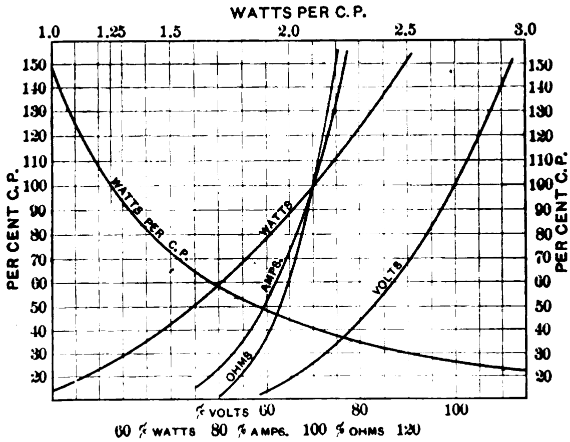


FIG. 24.—Performance of tungsten filament lamp

then

$$\frac{C_1}{C_2} = \left(\frac{e_2}{e_1}\right)^a$$

$$\frac{C_1}{C_2} = \left(\frac{V_1}{V_2}\right)^b$$

$$\frac{W_1}{W_2} = \left(\frac{V_1}{V_2}\right)^d$$

APPROXIMATE VALUES OF EXPONENTS

	a	*b*	*d*
Carbon...........	1.58	5.55	2.05
Gem.............	1.57	4.80	1.75
Tantalum.........	1.67	4.35	1.74
Tungsten.........	1.75	3.68	1.59

Values of the exponents are given not only for tungsten but for carbon, gem and tantalum as well, for purpose of comparison.

A series of values showing relation between voltage and candle-power variation for the four types of lamps has been calculated, and shows the great advantage which the metallic filament lamps, particularly the tungsten, possess over the carbon lamp.

Per cent change in voltage		Per cent change in candle-power			
		Carbon	Gem	Tantalum	Tungsten
Increase above normal	10	69.8	58.0	51.4	42.1
	9	61.4	51.3	45.5	37.4
	8	53.4	44.7	39.8	32.8
	7	45.6	38.4	34.2	28.3
	6	38.2	32.3	28.9	23.9
	5	31.1	26.4	23.6	19.7
	4	24.3	20.7	18.6	15.5
	3	17.9	15.2	13.7	11.5
	2	11.6	10.0	9.0	7.6
	1	5.7	4.9	4.0	3.7
Normal............		0	0	0	0
Decrease below normal	1	5.4	4.7	4.3	3.7
	2	10.6	9.3	8.4	7.2
	3	15.5	13.6	12.4	10.6
	4	20.3	17.8	16.2	13.9
	5	24.8	21.8	20.0	17.2
	6	29.0	25.7	23.6	20.4
	7	33.2	29.4	27.1	23.4
	8	37.1	33.0	30.5	26.4
	9	40.7	36.4	33.6	29.3
	10	44.3	39.7	36.8	32.2

An increase of 6 per cent in the voltage of a carbon lamp increases the per cent candle-power as much as an increase of 9 per cent in voltage of the tungsten lamp. While a tungsten lamp 10 per cent under voltage drops in per cent candle-power. only as much as a carbon lamp 7 per cent below normal. For a circuit where the regulation is poor, the tungsten lamp will be found to give much better satisfaction as far as variation in candle-power is concerned than the carbon lamp.

The size and length of filament required in lamps of various candle-powers and voltages varies considerably. For 110 volts the size and length varies from a diameter of 0.0013 in. and a total length of 17.4 in. for a 25-watt lamp to a diameter of 0.0060 in. and a total length of 37.56 in. for a 250-watt lamp.

The specific resistance of tungsten is about 46.5 ohms per mil-inch at a temperature corresponding to 1.25 watts per c.p. and about 9 per cent of this figure, or 4.19 ohms per mil-inch, at ordinary room temperature. This low cold resistance has led to a good deal of discussion as to the value of the starting current obtained upon closing the circuit of a tungsten lamp and its effect upon the filament.

The question is of particular importance when the lamps are

turned on and off continuously, as for example in flashing sign work. We have obtained experimentally the cooling curves of several sizes of tungsten lamps, which are shown herewith, plotted as resistance against time, Fig. 25. As would be expected, the larger lamps cool much more slowly than the smaller ones, as shown by the drop in resistance. It takes the 250-watt lamp, burning at 1.25 watts per c.p., 58 seconds after being turned off, to fall to 200 per cent of its initial cold resistance, while it takes the 60-watt lamp only 20 seconds, the 25-watt lamp about 11 seconds and the small low voltage sign lamp a little over six seconds. The filament of the latter lamp is actually heavier than that of the 25-watt lamp, but, being much shorter, cools

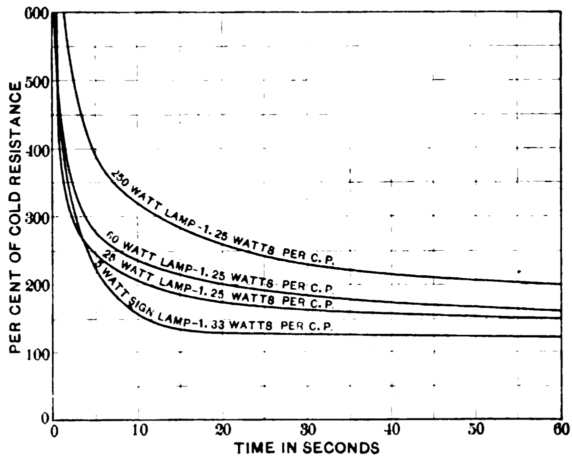


Fig 25.—Cooling curves of tungsten lamps

more rapidly by conduction of heat by the terminals and anchor.

In ordinary flashing sign work, four seconds can be assumed as an average period of flashing; this would allow the sign lamp to drop to only 250 per cent of its cold resistance between flashes, or the ratio of hot and cooling resistance when flashed in this way would be about one to four. This would act to greatly reduce the over-shooting effect.

From tests conducted on a few lamps flashed at various intervals, it is so far believed that flashing will have no injurious effect on the lamps in regard to life performance.

Having now covered the general method of manufacturing the tungsten lamp and a few of its characteristics we may turn our attention to the reason of its high efficiency.

A body at any temperature other than absolute zero will radiate energy in all wave lengths from zero to infinity, having a maximum radiation at a wave length which varies with the temperature. At low temperatures the actual amount of energy radiated is very small, and beyond narrow limits on either side of the maximum is infinitesimal.

The general distribution of energy so radiated is shown by the curves in Fig. 26. The total amount of energy radiated in a given time is represented by the total area under the curve and has been found to increase as the difference of the fourth powers of the temperature of the radiating body and the temperature of its surroundings. Not only does the actual rate of energy

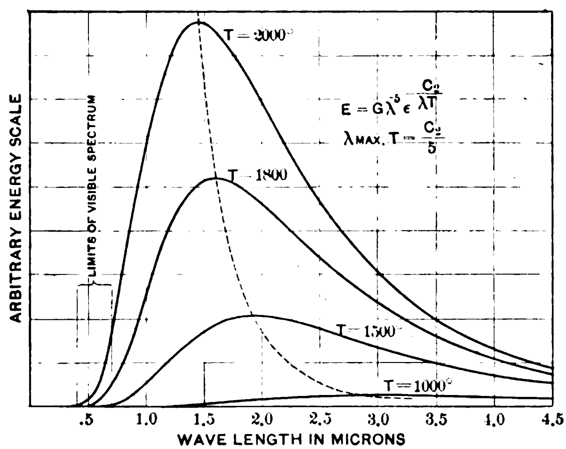


FIG. 26.—Black body radiation

radiation vary as a function of the temperature, but the manner in which the energy is radiated also changes. This change takes place as shown by the shift in the maximum point of the curves plotted for the radiation of a body at different temperatures. The radiation from most bodies follows a very complex law and has been thoroughly investigated only for a complete radiator or theoretical black body, which is represented in the curves shown. The same general law holds for other bodies as well as the theoretical black body considered.

Referring to the energy-wave length curves the area under the curves represents the total energy radiated by the body at the several temperatures. The visible spectrum which includes only the wave lengths capable of exciting the retina of the eye

represents but a small portion of the total range of radiation and the energy radiated in the visible spectrum represents a still smaller portion of the total amount of energy radiated. The ratio of the energy radiated in the visible spectrum to the total energy radiated is an indication of the luminous efficiency and since the maximum point of the energy curve shifts toward the visible spectrum, as the temperature rises, as shown by the dotted line, the luminous efficiency increases with the temperature.

It we could secure a black body capable of operating at extremely high temperatures and a means of producing such temperature we would find a limit to our efficiency of light production at about 5000 deg. absolute at which point the maximum of the energy curve would coincide with the maximum of the sensibility curve of the eye at about the middle of the visible spectrum. If the temperature could be raised still further the luminous efficiency would decrease, as the maximum of the energy curve would then move toward the ultra violet. Consequently we see that under ordinary conditions we can raise the luminous efficiency of a body by raising its temperature. In the attempt to secure high luminous efficiency by this means we are limited by the possibility of producing a substance capable of maintaining a high temperature without disintegration.

There is another important property of some substances which has made the present high commercial efficiency of the metallic filament lamps possible. The property referred to is that of selective radiation in the short wave lengths.

We have used the term black body or complete radiator to describe a body which will radiate at any temperature a maximum amount of energy in every wave length. Such a body would also be a complete absorber and would therefore absorb all energy incident upon it. A body, which is not a complete radiator, will at a given temperature radiate less energy in each wave length than a black body at the same temperature. If the energy radiated in each wave length is reduced by a constant proportion, the ratio of energy radiated in the visible spectrum to the total energy radiated will be the same as that of a black body, and the luminous efficiency would be the same as that of a black body at the same temperature. Such a body is termed a gray body, and in place of absorbing all energy, which falls upon it, it would reflect a constant percentage of each wave length.

If a body not only radiates less energy than a black body at

the same temperature, but in addition radiates a relatively larger proportion in one part of the spectrum than in another, compared to the black body it may be said to radiate selectively in that part of the spectrum. If the body radiates selectively in the short wave lengths the luminous efficiency will be higher than that of a black body at the same temperature. We would expect to find in the case of such a body that the absorption of energy would not be the same for different wave lengths but that the body would absorb a greater proportion of those wave lengths which it would radiate selectively when heated. A comparison of the reflecting power at different wave lengths for different substances is very interesting in showing how it is

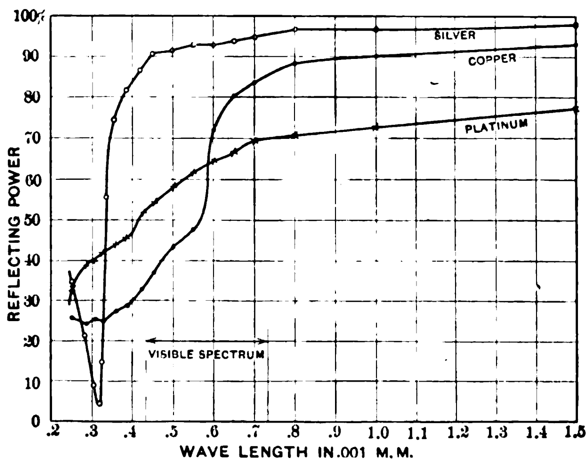


FIG. 27.—Percentage of energy of different wave lengths reflected from silver, copper and platinum

possible to gain in efficiency of light production by employing materials capable of selective radiation. Fig. 27 shows the percentage of energy of various wave lengths reflected from several different substances. A black body would have zero reflecting power throughout, a gray body a constant per cent throughout while a body capable of selective radiation a varying per cent. All the metals shown here have a tendency to reflect less energy in the visible spectrum than in the infra red, where the reflecting power rises to a very high value. Consequently since they absorb relatively more energy of the visible spectrum, they would, when heated, tend to radiate relatively more energy in the same part of the spectrum, and would therefore be found

to be more efficient luminous radiators than a black body at the same temperature. The relative percentage of energy in the visible spectrum to total energy at different temperatures can

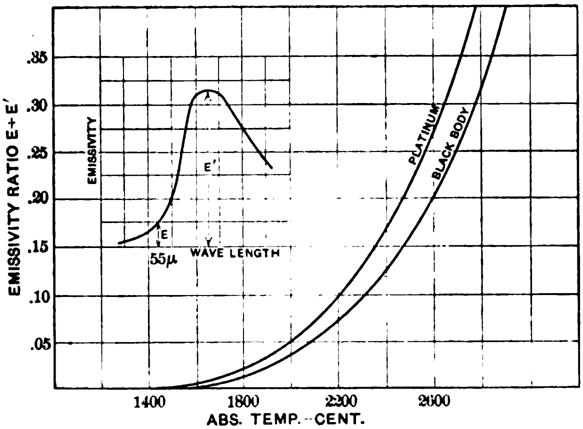


FIG. 28.—Selective radiation of platinum

be represented roughly by the ratio of the ordinate of the energy curve at 0.55 micron in the visible spectrum to the maximum ordinate. The curves shown in Fig. 28 indicate this ratio for various temperatures of a black body, and of platinum, showing the selective radiation of platinum in the shorter wave lengths. While the curves for tungsten are not available they should possess the same general characteristics as the metals shown.

Another way of showing the selective radiation is by means of actual energy curves taken through the range of principal radiation. Fig. 29 shows a series of curves determined by the Bureau of Standards showing the energy distribution of various filament materials when operated so that the light distribution is practically the same throughout the visible spectrum. It can be shown that the temperature of the tungsten filament in this comparison is at least as low as that of the carbon filament so

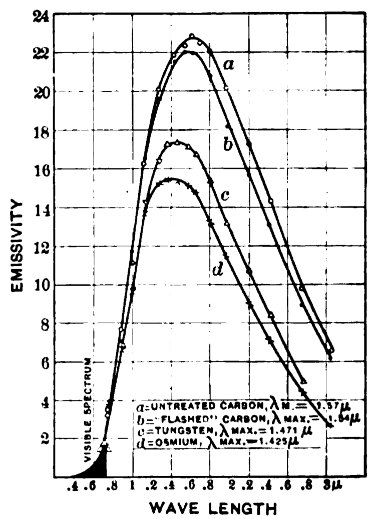


FIG. 29.—Curves of energy distribution of filament materials

that, under actual working conditions, the difference between the energy curves would be still more striking since a further gain in luminous efficiency is made possible by the higher normal operating temperature of the tungsten filament.

High commercial efficiency of incandescent lamps cannot be expected to result from high temperature alone but from a combination of high temperature with a property of selective radiation. The possibility of operating a filament at a high temperature is a very good feature but the disintegration of the filament, which increases more and more rapidly as the temperature rises places an upper limit on the temperature at which

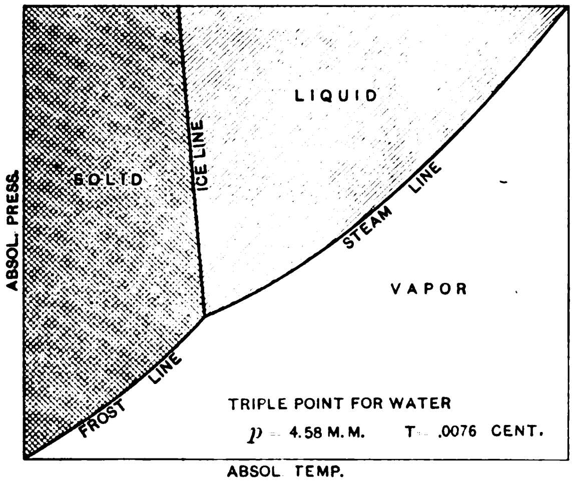


FIG. 30.—Pressure-temperature diagram of water

it is possible to operate a filament and still obtain a commercial life, so that we cannot look to high temperature alone for a solution of the problem. The temperature at which it is possible to operate a filament, and secure a reasonably long life, depends not so much on the melting point as upon the ability to withstand surface evaporation in a high vacuum.

The conditions that exist in a lamp of high exhaustion in regard to melting and vaporization are rather interesting. If we plot a pressure temperature diagram for any substance we find that the three states of the substance will be represented by three areas bounded by three curves which we would call, in speaking of water, the steam line, the ice line and the frost

line. See Fig. 30. The intersection of these three curves gives us the location of the " triple point ", or the pressure and temperature at which it would be possible to have the substance existing in these three states at the same time.

In an incandescent lamp bulb the pressure is exceedingly low, something of the order of 0.001 mm. of mercury, so that we may believe while not being able to prove conclusively that at normal operating temperatures of the filament we are working on a part of the diagram below the triple point, there would therefore be a tendency for the material to evaporate slowly from the filament surface, as it apparently does. That the

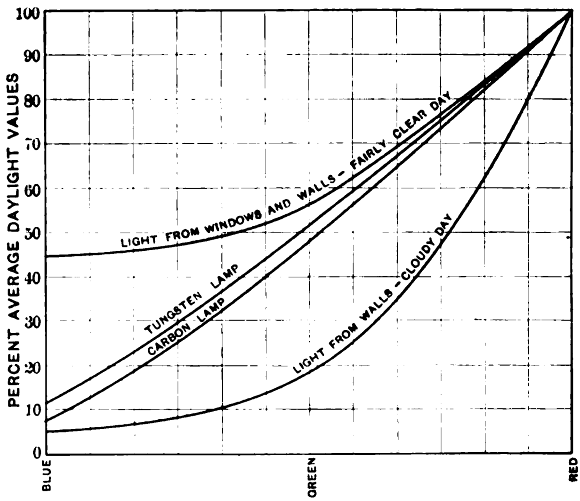


Fig. 31.—Color composition of various lights

temperature of commercial operation is not dependent upon the actual melting point may be shown by the rapid disintegration of a carbon filament if operated at the normal temperature of a tungsten filament in spite of the fact that the true melting point of carbon is probably higher than that of tungsten.

The tungsten lamp is, because of its selective radiation and higher filament temperature, superior to the older types of incandescent lamps in the quality of its light. Under normal working conditions the tungsten favors the shorter wave lengths through the visible spectrum, giving relatively more blue radiation than the carbon lamp for an equal amount of red. The accompanying curves, Fig. 31, show the relative amounts of red,

green, and blue in several types of lamps compared to daylight. The term, daylight, as ordinarily used is rather indefinite, as the proportion of red, green and blue in the light from a cloudy sky is different from that of a clear blue sky, which, again is different from that of direct sunlight. The comparison in this case is made to average outdoor daylight, as obtained from careful observation over a considerable length of time, and which is represented as 100 per cent red, 100 per cent blue and 100 per cent green.

I have drawn two other curves, which may be taken to represent the composition of light as it actually may exist in interior daylight illumination. Due to the reflection from surrounding objects, both without and within, it is usual to find the light in a room possesses a markedly different composition from the average light received directly from the sky.

An object in a room in day time is illuminated for the most part by light reflected from the walls of the room, except, of course, if it is directly in front of and close to a window. At night, with an artificial source of light within the room, the objects are illuminated for the greater part with light directly from the artificial source. The artificial source of light should therefore be of such character as to illuminate the objects in the room by its direct rays with a light of the same average quality or color value as that which illuminates them by diffuse reflection from walls and furnishings during the day. The nearer the color curve of an illuminant approaches that of the average interior light of a particular room during the day the more natural will the room appear if illuminated with such a source of light.

The question of frequency and flicker is one which often arises in connection with the use of the tungsten or other high-efficiency lamps on low-frequency power circuits. The candle-power of an incandescent body varies with the temperature. The temperature depends upon the relative rate at which energy is put into the filament and the rate at which it is dissipated by radiation, conduction and convection. When the energy is supplied at a changing rate, as by an alternating current, the temperature will fluctuate in synchronism with the power wave, or at double the frequency of the supplied e.m.f. The amount of variation in temperature during one cycle will depend upon the ressistance temperature coefficient of the filament, its mass, diameter, specific heat, emissivity, and upon the wave shape and frequency of the energy supplied. If the frequency is low enough

the temperature will fluctuate over wide limits. The amount of temperature fluctuation decreases greatly as the frequency increases, due to the thermal capacity of the filament. When the frequency of the electric circuit reaches about 25 to 27 cycles the flicker of most incandescent lamps giving usual intensities of illumination becomes imperceptible, although, it may in some cases be detected momentarily by rapidly moving the eyes from one object to another. The flicker effect at a given frequency will be more noticeable with a thin filament than with a heavier one of the same material since the quantity of heat contained at a given temperature varies as the mass or diameter squared, while the radiating surface varies only as the diameter to the first power.

In comparing tungsten and carbon filaments of the same diameter we must bear in mind that the higher specific heat of carbon tends to maintain its temperature more nearly constant with varying power input than in the case of the tungsten, while its higher emissivity tends to produce a more marked variation. Since, however, the diameter of a tungsten filament is less than that of a carbon filament for same voltage and candle-power, the carbon lamp is actually found to show a less tendency to produce visible flicker.

The question of flicker further involves the ability of the eye to detect a rapid variation in luminous intensity and it has been shown that the eye becomes less sensitive to the effect of flicker, as the average intensity of the illumination decreases. We have found, from experimental work, which is as yet not complete enough for more extended discussion, that the critical frequency at which it is possible to detect flicker varies as a function involving the product of the average intensity of illumination and the per cent variation in intensity. Thus the question as to whether a given lamp will show a flicker when operated at a certain frequency depends a great deal upon the average intensity of the illumination produced.

If we judge the flicker of a lamp at a certain low frequency by viewing a large surface illuminated by the lamp we would find that as the distance between the lamp and the surface increased the flicker would become less and less perceptible, diminishing with the intensity of illumination until, beyond a certain value of illumination no flicker could be detected. This characteristic of the eye enables comparatively low frequencies to be used successfully with low values of illumination.

The question of flicker is perhaps of most importance in connection with street series lighting, since, in ordinary multiple lighting, higher frequencies are usually employed. The street series tungsten should prove capable of successful operation at comparatively low frequencies for two reasons; first, the filament is heavy, which tends to reduce the variation in candle-power throughout a cycle; and second, the low value of illumination generally used in street lighting would tend to make any varaition in intensity of illumination less perceptible to the eye.

A paper presented at a joint meeting of the American Society of Mechanical Engineers and the American Institute of Electrical Engineers, New York, March 8, 1910.

(Subject to final revision for the Transactions.)

TEST OF A 15,000-KW. STEAM-ENGINE-TURBINE UNIT

BY H. G. STOTT AND R. J. S. PIGOTT

During the year 1908 it became apparent that owing to the cost of increasing traffic in the New York subway, it would be necessary to have additional power available for the winter of 1909-1910.

The power plant of the Interborough Rapid Transit Company, which supplies the subway, is located on the block bounded by 58th and 59th Streets, and by 11th and 12th Avenues, adjacent to the North River; it contains nine 7500-kw. (maximum rating) engine units, besides three 1250-kw. 60-cycle turbine units which are used exclusively for lighting and signal purposes.

The 7500-kw. units consist of Manhattan-type compound Corliss engines, having two 42-in. horizontal high-pressure cylinders and two 86-in. vertical low-pressure cylinders. Each horizontal high-pressure cylinder and vertical low-pressure cylinder has its connecting rod attached to the same crank, so that the unit becomes a four-cylinder 60-in. stroke compound engine with an overhanging crank on each side of a 7500-kw. maximum rating 11,000-volt, three-phase, 25-cycle generator. The generator revolving field is built up of riveted steel plates of sufficient weight to act as a flywheel for the two engines connected to it. This arrangement gives a very compact two-bearing unit. The valve gear on the high-pressure cylinders is of the poppet type, and on the low-pressure of the Corliss double-ported type.

The condensing apparatus consists of barometric condensers, arranged so as to be directly attached to the low-pressure exhaust nozzles, with the usual compound displacement circulating pump and simple dry-vacuum pump.

These engines and generator units are in general probably the most satisfactory large units ever built, as five years' experience with them has proved; their normal economic rating is 5000 kw., but they operate equally well (water rate excepted) on 8000 kw. continuously.

In considering the problem of how to get an additional supply of power, every available source was considered, but by a process of elimination only two distinct plans were left in the field.

The electric transmission of power from a hydraulic plant was first considered, but owing to the high cost of a double transmission line from the nearest available water power, and the impossibility of getting reliable service (that is, service having a maximum total interruption of not more than ten minutes per annum) from such a line, further consideration of this plan was abandoned.

The gas engine, while offering the highest thermo-dynamic efficiency at the same time required an investment of at least 35 per cent more than an ordinary steam-turbine plant with a probable maintenance and operation account of from four to ten times that of the steam turbine.

The reciprocating-engine unit of the same type as those already installed, was rejected in spite of its most satisfactory performance, on account of the high first cost and small range of economical operation. Reference to Fig. 1, Series A will show that the economic limits of operation are between 3300 kw. and 6300 kw.; beyond these limits the water rate rises so rapidly as to make operation undesirable under this condition, except for a short period during peak loads.

The choice was thus narrowed down to either the high-pressure steam turbine or the low-pressure steam turbine. There was sufficient space in the present building to accommodate three 7500-kw. units of the high-pressure type, or a low-pressure unit of the same size on each of the nine engines, so that the questions of real estate and building were eliminated from the problem.

The first cost of a low-pressure turbine unit is slightly lower than that of a high-pressure unit, due to the omission of the high pressure stages and the hydraulic governing apparatus, but the cost of the condensing apparatus would be the same in both cases. The foundations and the steam piping in both cases would not differ greatly. The economic results, so far as the first cost is concerned, would then be approximately the same, if we consider the general case only; but in this particular in-

stance the installation of high-pressure turbines would have meant a much greater investment for foundations, flooring, switchboard apparatus, steam piping and water tunnels, amounting to an addition of not less than twenty-five per cent to the first cost.

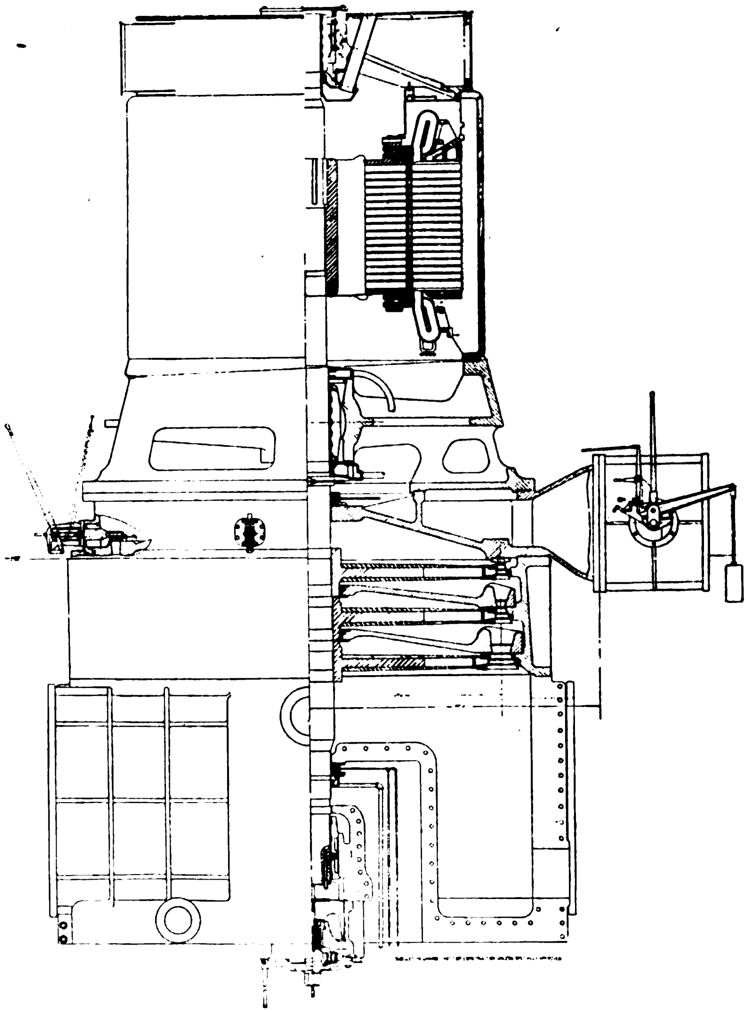
The general case of displacing reciprocating engines and installing steam-turbine units in their place was also considered. The best type of high-pressure turbine plant has a thermal efficiency approximately 10 per cent better than the best reciprocating-engine plant, but the items of labor for operation and for maintenance, together with the saving of about 85 per cent of the water for boiler-feed purposes and the 10 per cent of coal, reduce the relative operating and maintenance charges for the steam-turbine plant to 80 per cent, as compared to 100 per cent for the reciprocating-engine plant.

Assuming that the reciprocating engine plant is a first-class one and has been well maintained, about 20 per cent of its original cost (for engines, generators and condensers) may be realized on the old plant and so credited to the cost of the high-pressure turbine plant. But on the other hand, if the high-pressure turbine installation is to receive credit for the second-hand value of the engines, it must also have a debit charge for 100 per cent of the original reciprocating-engine plant which it displaced. The relative investments, therefore, upon this basis would be approximately equal for the high-pressure or the low-pressure turbine; but 80 per cent of the cost of the original engine plant would have to be charged against the high-pressure turbine plant, as against an actual increase in value (to the owner) of the engine by reason of its improved thermal efficiency, due to the addition of the low-pressure turbine.

The preliminary calculations, based upon the manufacturers' guarantees for the low-pressure and high-pressure turbines, showed that the combined engine-turbine unit would give at least 8 per cent better efficiency than the high-pressure turbine unit, so that it was finally decided to place an order for one 7500-kw. (maximum rating) unit, as by this means we would not only get an increase of 100 per cent in capacity, but at the same time give the engines a new lease of life by bringing them up to a thermal efficiency higher than that attained by any other type of steam plant.

The turbine installed is of the vertical three-stage impulse type having six fixed nozzles and six which can be operated by

hand, so as to control the back pressure on the engine, or the division of load between engine and turbine. An emergency overspeed governor, which trips a 40-in. butterfly valve on the



Elevation and part section of low pressure turbine unit

steam pipe connecting the separator and the turbine and at the same time the 8-in. vacuum breaker on the condenser, is the only form of governor used. The footstep bearing, carrying the weight of the turbine and generator rotors, is of the usual design sup-

plied with oil under a pressure of 600 lb. per sq. in. with the usual double system of supply and accumulator to regulate the pressure and speed of the oil pumps.

The condenser contains approximately 25,000 sq. ft. of cooling surface arranged in the double two-pass system of water circulation with a 30-in. centrifugal circulating pump having a maximum capacity of 30,000 gal. per hr. The dry vacuum pump is of the single-stage type, 12-in. and 29-in. by 24-in., fitted with Corliss valves on the air cylinder. The whole condensing plant is capable of maintaining a vacuum within 1.1 in. of the barometer when condensing 150,000 lb. of steam per hr. when supplied with circulating water at 70 deg. fahr.

The electric generator is of the three-phase induction type, star-wound for 11,000 volts, 25 cycles and a speed of 750 rev per min. The rotor is of the squirrel-cage type with bar winding connecting into common bus-bar straps at each end. This type of generator was chosen as being specially suited to the conditions obtaining in the plant.

With nine units operating in multiple, each one capable of giving out 15,000 kw. for a short time, operating in multiple with another plant of the same size, it is evident that it is quite possible to concentrate 270,000 kw. on a short circuit. If we proceed to add to this, synchronous turbine units of 7500-kw. capacity, which, owing to their inherently better regulation and enormous stored energy, are capable of giving out at least six times their maximum rated capacity, the situation might soon become dangerous to operate, as it would be impossible to design switching apparatus which could successfully handle this amount of energy. The induction generator, on the other hand, is entirely dependent upon the synchronous apparatus for its excitation, and in case of a short circuit on the bus-bars would automatically lose its excitation by the fall in potential on the synchronous apparatus.

The absence of fields leads to the simplest possible switching apparatus, as the induction generator leads are tied in solidly through knife switches, which are never opened, to the main generator leads. The switchboard operator has no control whatever over the induction generator, and only knows it is present by the increased output on the engine generator instruments.

The method of starting is simplicity itself—the exciting current is put on the engine generator *before* starting the engine,

and then the engine is started, brought up to speed and synchronized in exactly the same way as before. While starting in this way, the induction generator acts as a motor until sufficient steam passes through the engine to carry the turbine above synchronism, when it immediately becomes a generator and picks up the load. Three of these 7500-kw. low-pressure turbine units have been installed and tests run on Nos. 1 and 2. No. 3, having been just started, has not yet been tested.

Instead of inserting in this paper the enormous accumulation of data incident to these tests, we have divided the paper into two parts in the hope that it would thus be more accessible for reference, the first part giving the reasons for adopting this particular type of apparatus, with a brief description of the plant and a summary of the results obtained, and the second part containing all the principal data acquired during the tests, with sufficient explanation to make their meaning clear without reference to the text.

The tables and curve sheets are as follows:

Series A: Engine tests made in connection with acceptance tests, and also later to determine best conditions for operation.

Series B: Calculations and data furnished by turbine manufacturer to determine probable results when combined with engine data obtained in Series A.

Series C: Tests on No. 1 combined unit. This unit was hurriedly put into commission in order to obtain results to determine future developments. To get the piping done, old riveted steel pipe was used which was very leaky under vacuum. Results are valuable however as showing the effect of vacuum on performance as compared to Series E and F. Quality of steam entering turbine also poor.

Series D: Tests of No. 2 unit, with poor vacuum and poor quality of steam entering turbine.

Series E and F: Tests on No. 2 combined unit: conditions of vacuum and quality of steam entering turbine nearly standard, so that corrections are small.

In all results, except where specially noted, moisture corrections are simple corrections, *i.e.*, for each per cent of moisture only one per cent correction has been made. Vacuum corrections for the combined unit are 1 lb. for each inch variation from 28.5 in. when referred to 29.92 in. barometer.

The net results obtained by the installation of low-pressure turbine units may be summarized as follows:

a An increase of 100 per cent in maximum capacity of plant.

b An increase of 146 per cent in economic capacity of plant.

c A saving of approximately 85 per cent of the condensed steam for return of the boilers.

d An average improvement in economy of 13 per cent over the best-high pressure turbine results.

e An average improvement in economy of 25 per cent (between the limits of 7000 kw. and 15,000 kw.) over the results obtained by the engine units alone.

f An average unit thermal efficiency between the limits of 6500 kw. and 15,500 kw. of 20.6 per cent.

TABLE 1 SERIES A, ENGINE TESTS

No. of test	Eng. load kw.	Steam pressure lb. gauge	Steam temperature deg. fahr.	Steam superheat deg. fahr.	Receiver pressure (from temp.) lb. gauge	Vacuum std. in. 29.92 in mercury	Quality of steam per cent	Water per hr. lb.	Dry steam per hr. lb.	Rec. drain per hr. lb.	Steam to auxiliary lb.	Inject water temp. deg. fahr.	Disch. water temp. deg. fahr.	i.h.p. high-pressure h.p.	i.h.p. low pressure h.p.	i.h.p. total h.p.	Dry steam per kw-hr. lb.	Dry steam per i.h.p. hr. lb.
25	3100	180.1	388.3	9.7	9.13	28.81	100.55	56040	56349	2989	1517	36.8	55.7	2173	2306	4479	18.18	12.58
22	4008	176.7	383.9	5.7	16.87	27.99	100.32	68190	68407	4882	1866	38.4	58.3	2699	2815	5514	17.07	12.42
24	4977	174.4	387.8	10.6	21.7	28.00	100.58	85369	85865	5273	2949	36.8	65.3	3264	4076	7341	17.25	11.70
21	5984	173.9	387.5	10.5	25.9	28.00	100.60	103896	104519	6031	1699	37.73	69.5	3717	4714	8431	17.47	12.40
23	6772	173.3	385.5	8.7	30.0	27.71	100.50	124702	125326	6060	2091	37.7	70.4	4346	5732	10078	18.51	12.37
27	4992	173.9	387.3	10.5	10.44	28.11	100.60	89525	99062	5367	1826	37.76	72.66	3770	5184	6954	18.04	12.95
26	4970	173.2	386.1	9.4	15.21	28.00	100.53	86267	86724	5518	1728	35.9	61.1	3443	3452	6895	17.45	12.58
29	4976	174.9	386.9	9.4	20.41	28.00	100.53	85557	86010	5294	3034	38.1	75.0	3124	3722	6846	17.29	12.59
28	4970	174.3	388.8	11.7	25.35	28.02	100.66	85933	86501	4890	663	36.7	72.6	2982	4127	7109	17.42	12.17
31	3988	177.7	387.5	8.9	32.62	—	100.51	109317	109874	5948	—	—	—	2625	2372	4997	27.55	21.99
32	4980	176.2	386.7	8.7	36.93	—	100.50	128056	128695	6352	—	—	—	2835	3333	6168	25.84	20.88
30	4961	148.2	372-0	7 0	21.06	28.04	100-40	88041	88394	5082	1284	37.46	72.4	3068	4019	7087	17.82	12.48

TABLE 2—SERIES A

No. of test	Eng load kw.	B.t.u. added per pound water	B.t.u. rej. per pound water	Eff. Rankine per cent	Eff. thermal per cent	$\frac{Eff_T}{Eff_R}$ per cent	B.t.u. drains per cent	B.t.u. con's'r and rad'n loss per cent	B.t.u. mech. elec. loss per cent	Remarks
25	3100	1205	840	30.3	15.7	51.7	0.9	71.4	12.0	
22	4008	1202	865	28.0	16.7	59.6	1.3	70.0	"	
24	4977	1204	866	28.1	16.5	58.1	1.2	70.3	"	
21	5984	1204	866	27.1	16.3	58.2	1.1	70.6	"	
23	6772	1203	875	28.3	15.4	56.4	1.0	71.6	"	
27	4992	1205	865	28.2	15.8	56.0	1.0	71.2	"	
26	4970	1204	866	28.1	16.3	58.1	1.2	70.5	"	
29	4976	1205	866	28.1	16.4	58.6	1.2	70.4	"	
28	4970	1206	866	28.2	16.4	58.1	1.1	70.5	"	
31	3988	1205	1017	15.6	10.3	66.2	1.1	76.6	"	Non-condensing
32	4980	1204	1017	15.5	11.0	71.1	1.0	76.0	"	Non-condensing
30	4961	1200	875	27.1	16.0	59.7	1.1	70.9	"	

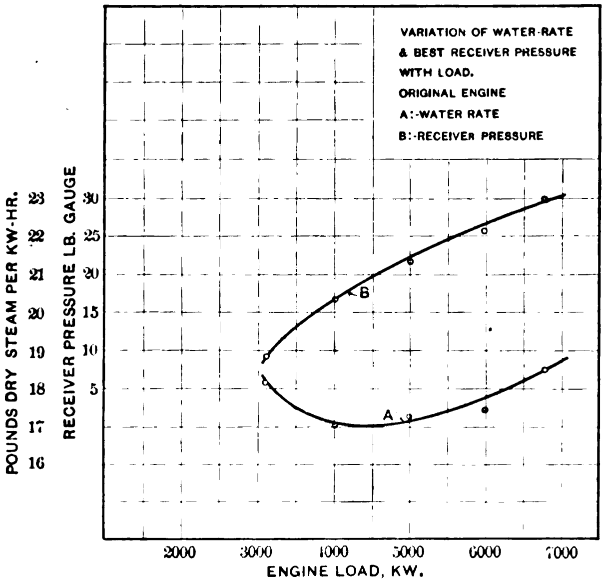


FIG. 1.—Series A

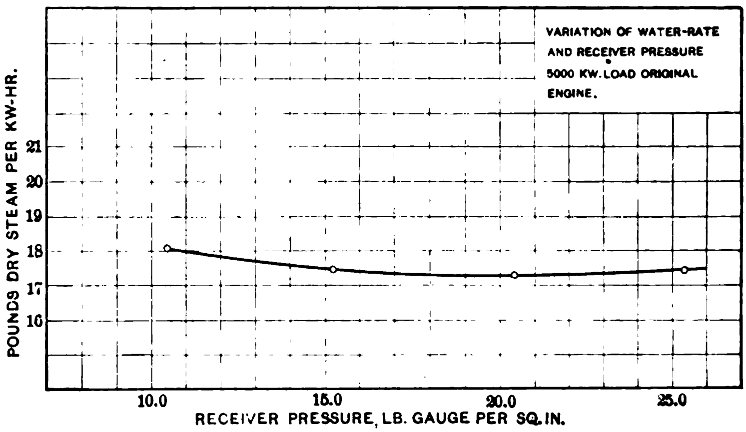


FIG. 2.—Series A

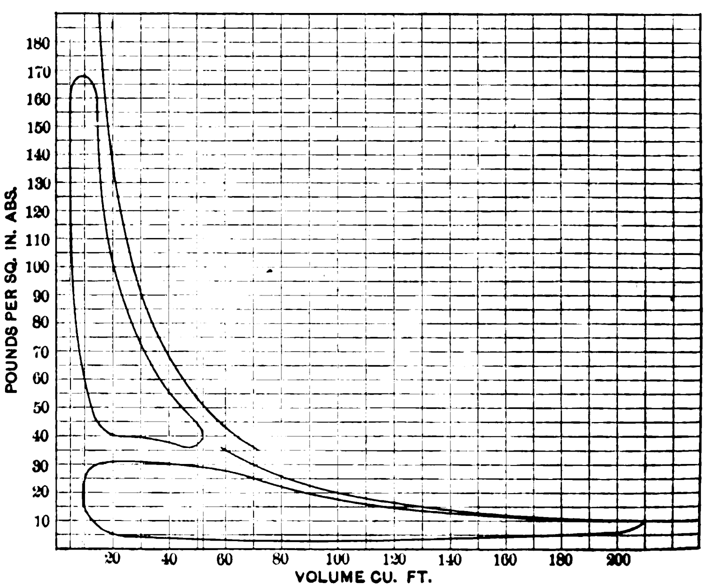


FIG. 3.—Series A, test 29

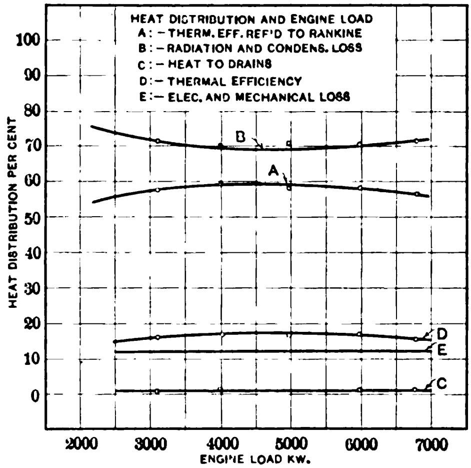


FIG. 3a.—Series A

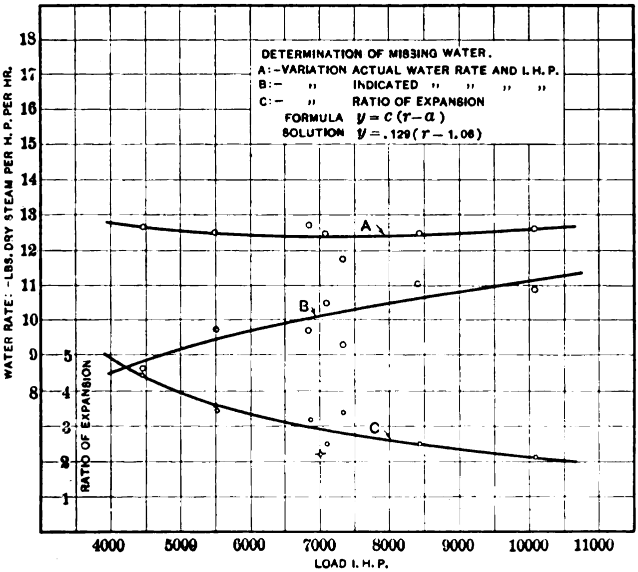


FIG. 4.—Series B

TABLE 3 SERIES B

No. test	Load kw.	i.h.p.	Ratio high press. / low press. i.h.p.	P_a lb. per sq. in. abs.	P_c lb. per sq. in. abs.	V_a cu. ft.	V_c cu. ft.	W_a lb. per cu. ft.	W_c lb. per cu. ft.	Steam per stroke high press. card lb.	r	y	Indic. water rate per i.h.p. lb. per hr.	Actual water rate per i.h.p. lb. per hr.	Actual water rate per kw-hr. lb. per hr.	Receiver press. per lb. sq. in. abs.	Exhaust press. lb. per sq. in. abs.	Steam press. lb. per sq. in. abs.	Steam press. total water lb. per hr.
25	3100	4479	0.943	137.32	66.12	10.78	7.56	0.3058	0.1544	2.131	4.80	0.469	8.57	12.59	18.18	19.8	0.9	191.5	56349
22	4008	5515	0.95[illegible]	143.0	65.3	13.77	9.31	0.3176	0.1526	2.951	3.41	0.298	9.64	12.41	17.07	31.6	1.0	192.8	68407
29	4976	8466	0.840	142.4	73.8	16.64	9.30	0.3163	0.1709	3.670	3.11	0.302	9.65	12.56	17.29	36.4	1.0	190.9	86010
24	4977	7341	0.801	141.8	75.7	17.13	9.30	0.3151	0.1751	3.769	3.32	0.265	9.24	11.69	17.25	35.1	0.9	191.0	85865
21	5984	8431	0.789	141.8	74.1	21.48	9.29	0.3142	0.1716	5.154	2.42	0.128	11.00	12.40	17.47	40.6	0.9	191.0	104519
23	6772	10078	0.759	140.6	89.0	25.40	9.29	0.3126	0.2037	6.080	2.04	0.154	10.86	12.44	18.51	44.7	1.0	190.9	125326
31	3988	5900	1.403	143.7	72.2	19.83	7.53	0.3191	0.1675	5.058	3.11	0.206	15.43	18.62	27.55	47.3	14.7	192.2	109874
32	4981	7004	0.807	143.7	75.8	23.44	7.57	0.3191	0.1753	6.154	2.21	0.155	15.81	18.28	25.84	51.6	14.7	189.7	128695
Assumed cards, variable nozzle pressure																			
A	4050	5936	1.04	187.8	82.5	10.93	4.70	0.4107	0.1897	3.597	4.73	0.474	12.00	17.69	25.92	39.7	7.0	215	105000
B	5590	8192	1.05	182.2	96.0	16.45	"	0.3991	0.2186	5.537	3.14	0.268	12.18	15.45	22.63	46.0	10.0	"	126600
C	6710	9836	1.07	176.0	119.5	22.80	"	0.3862	0.2685	7.55	2.27	0.156	13.62	15.98	23.40	52.2	13.5	"	157300
D	7370	10792	1.10	168.6	122.8	29.83	"	0.3708	0.2753	9.71	1.73	0.087	16.30	17.72	25.95	58.5	18.0	"	191100
E	7740	11336	1.05	160.9	136.2	37.60	"	0.3549	0.3034	11.92	1.31	0.033	18.91	19.54	28.61	64.7	23.0	"	221400
Assumed cards, constant nozzle pressure																			
F	3875	5676	1.12	182.2	136.2	16.45	"	0.3991	0.3034	5.140	3.14	0.268	16.31	20.69	30.30	64.7	16.0	"	117400
G	5795	8484	0.988	176.0	"	22.80	"	0.3862	"	7.374	2.27	0.156	15.57	18.00	26.38	"	"	"	152700
H	7190	10540	0.974	168.6	"	29.83	"	0.3708	"	9.633	1.73	0.087	16.45	17.88	26.20	"	"	"	188500
I	8200	12008	0.938	160.9	"	37.60	"	0.3549	"	11.92	1.31	0.033	17.86	18.45	27.04	"	"	"	221700

TABLE 4—SERIES B

Assumed cards low pressure exhaust quality data											
No.	Water p. hr. lbs.	High press. steam to low press cylinders per cent	Moist-ure at low press. admis-sion per cent	Admis-sion press. lb. per sq. in. abs.	Re-lief press. lb. per sq. in. abs.	Ex-haust press. lb. per sq. in. abs.	r	Qual-ity of low press. ex-haust per cent	Comb. qual-ity per cent	Dry steam turb. lbs. per hr.	
A	105000	93.2	2.5	37	9.5		2.76	90.6	84.4	88600	Variable nozzle press.
B	126600	94.3	3.0	43	14		2.47	90.9	85.7	108500	
C	157300	95.2	3.5	49	19		2.26	91.4	86.9	136700	
D	191100	95.9	4.0	55	24		2.10	91.6	87.8	167800	
E	221400	96.2	4.0	60	28		1.98	91.9	88.4	195600	
F	117400	96.8	3.0	60	20	17.5	3.30	90.8	84.5	99200	Constant nozzle press.
G	152700	95.7	3.5	"	20	"	2.94	90.5	85.5	130600	
H	188500	94.4	4.0	"	23	"	2.46	90.8	86.9	163800	
I	221700	93.1	4.0	"	27	"	1.98	91.6	88.7	196600	

Remarks and Formulae

Tests 21–29 inclusive, 8 hr.

Tests 31–32, 8 hr. atmospheric exhaust non-condensing.

$$\frac{\text{i.h.p.}}{\text{kw.}} = 1.465\,.$$

$$r = \frac{51.7}{V_a} \text{ for high-press. card } = \text{ ratio of expansion.}$$

$y = 0.129\ (r - 1.06) = $ missing water.

$w = $ Sp. density at p.

$$W_a \times V_a = W_1 \qquad W_c \times V_c = W_2 \qquad W_1 - W_2 = W_3$$

$$\frac{W_3 \times 60 \times 4 \times 75}{\text{i.h.p.}} = \text{i. w. r. at high press. cut-off.}$$

I. w. r. $\times (1 + y) = $ a. w. r. per i.h.p. hr.

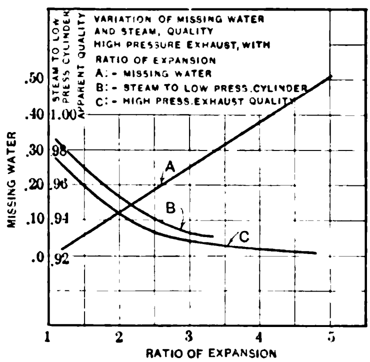


FIG. 5.—Series B

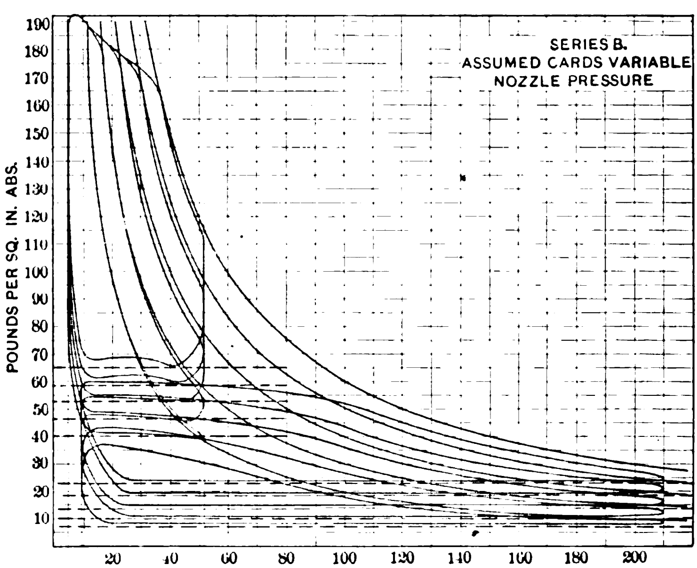


FIG. 6.—Series B

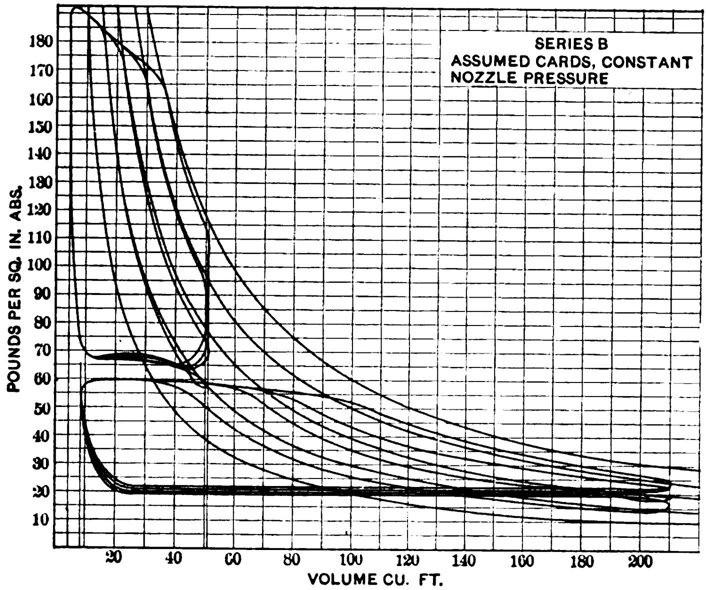


FIG. 7.—Series B

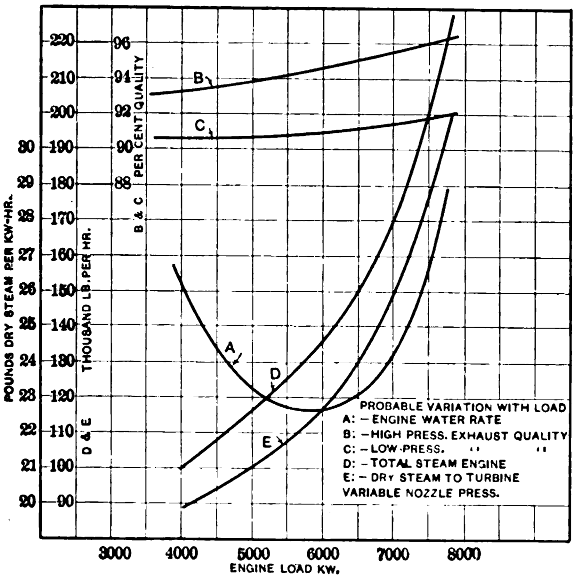


FIG. 8.—Series B

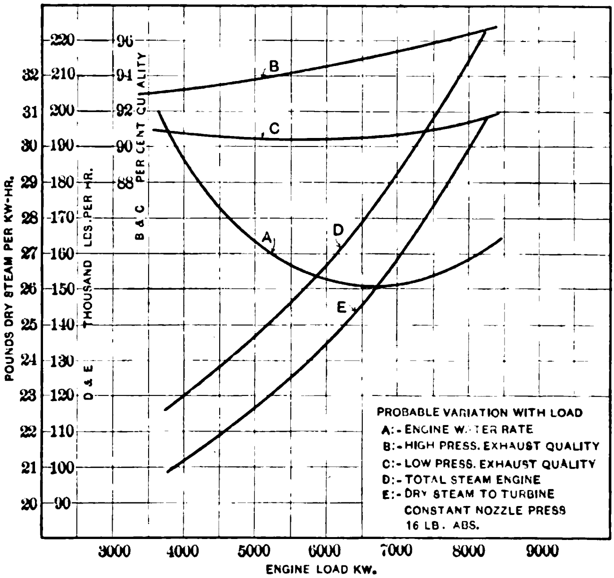


FIG. 9.—Series B

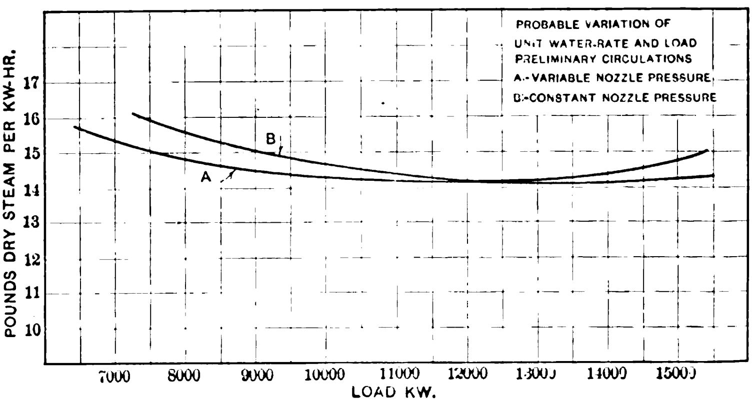


FIG. 10.—Series B

TABLE 5 SERIES C

Resume of observations — Corrected to 29.92 in. barometer and 14.7 lb. atmos.

		Loads			Pressures					Qualities		Water			Dry steam		Temperatures		
Test No.	Duration	Unit	Engine	Turbine	High press. steam	Receivers	Low press. steam	Low press. steam	Vacuum	High pressure steam	Low pressure turb.	Separator low pressure	Turbine discharge	Total unit	Turbine	Eng. and unit	Hot well cond.	Injection	Disch. circ. water
	hours	kw.	kw.	kw.	lb. gauge per sq. in.	lb. gauge per sq. in.	lb. abs. per sq. in.	lb. gauge per sq. in.	in mercury	Per cent	Per cent	lb. per hour	lb. per hour	lb. per hour	lb. per hour	lb. per hour	deg. fahr.	deg. fahr.	deg. fahr.
5	4	10220	6627	3690	174.4	36.2	12.72	—	28.03	97.08	90.89	3369	150170	153540	136500	149000	88.1	72.1	84.0
6	5	11320	6520	4870	173.4	35.7	17.22	1.52	28.34	96.96	94.09	2759	167190	169950	158200	164850	87.6	74.7	87.8
7	3	11150	6187	4960	173.4	33.9	17.36	2.66	28.55	97.06	90.17	1157	164945	166100	148350	161200	85.5	72.5	86.0
8	3	10970	6178	4840	170.2	49.6	17.36	2.66	28.44	97.15	88.62	654	161612	162270	143200	157700	86.9	74.4	86.6
9	2	11250	6560	4685	170.2	50.1	16.61	1.91	28.18	97.08	92.08	5830	164458	170290	151900	165300	87.8	72.8	86.3
10	1	12440	7060	5400	172.0	49.3	17.60	2.90	27.91	97.54	86.96	3133	185100	188230	161400	183600	89.5	72.0	83.3
11	2	8990	5195	3795	172.0	50.0	16.61	1.91	27.92	97.54	91.32	469	136850	137320	124890	133930	87.3	72.4	83.5
12	1	13240	7580	5610	172.6	48.8	17.06	2.36	27.99	98.32	85.06	6018	192290	198310	163500	194900	90.7	75.4	89.2
13	2	10240	6070	4220	172.0	47.1	16.80	2.10	27.98	98.50	91.05	825	156470	157290	142470	154900	88.2	72.8	83.8
14	2	11480	6140	5340	174.8	51.4	18.84	4.14	28.29	98.41	90.24	337	176210	176550	159010	173740	83.4	73.0	86.6
15	5	11504	6022	5468	170.8	48.1	19.45	4.75	27.51	97.83	95.15	—	167103	—	159000	—	91.8	78.2	93.5
16	7	11526	6314	5203	173.9	48.4	19.45	4.75	27.42	98.02	93.57	9633	167085	176718	157300	173200	92.9	78.6	91.5
17	5	11528	6084	5488	175.7	49.5	19.90	5.20	27.62	97.70	94.68	5111	179170	184301	169650	180100	83.4	73.6	86.7
18	6	10740	5916	4831	174.1	49.5	18.56	3.85	27.65	98.19	94.83	12554	149148	161702	141450	158750	89.7	72.8	83.6
19	6	14740	7830	6692	174.0	51.7	18.42	3.72	27.78	97.66	95.07	16404	201351	217755	191450	212700	90.9	72.2	88.2
20	4	14365	7373	6952	171.6	52.2	20.94	6.24	27.75	97.88	96.47	15423	196680	212103	189750	207750	90.3	72.6	93.7
21	6	10320	5632	4517	175.9	49.8	17.77	3.07	28.03	97.54	89.52	6486	144399	150885	129150	147100	87.8	72.5	84.4
23	6	13410	7460	5852	173.9	50.2	18.01	3.31	27.72	97.80	96.09	15760	195514	211274	188000	206800	91.1	73.0	87.0
24	6	12927	7033	5820	169.8	50.2	18.59	3.89	27.79	98.03	95.47	14439	173150	187589	165300	183950	89.8	73.3	86.8
25	6	9730	5142	4508	175.3	49.7	18.99	4.29	27.78	97.77	96.46	11189	134635	145824	129840	142600	88.8	72.3	82.8
26	6	11840	6470	5305	172.6	49.2	19.02	4.32	27.48	98.18	96.48	14090	161983	176073	156300	172900	88.2	73.1	84.9
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

TABLE 6 SERIES C

Test	Load	Results: Water rates (dry steam) Turbine, Actual	Engine, Actual	Unit, Actual		Unit moist corr	Unit total corr.		Guarantee and calculated water rates: Turbine, Constant nozzle pressure	Engine, Constant nozzle pressure	Unit, Constant nozzle pressure	Circ. water Ratio	Circ. water Total	Water rate unit equivalent	Remarks	Formulae and notes
	kw.	Lb. per kw-hr.	Lb. per kw-hr.	Lb. per kw-hr.		Lb. per kw-hr.	Lb. per kw-hr.		Lb. per kw-hr.	Lb. per kw-hr.	Lb. per kw-hr.	C.W. / Dry st.	Gal. per min.	Lb. per i.h.p. hr. c.n.p.		
5	10220	36.80	22.48	14.57		14.0	13.53		28.42	26.03	14.42	89.0	26740	8.85	Varying nozzle press.	$27 = \frac{17}{4+[1+(1-12)]5}$
6	11320	32.34	25.30	14.45		14.1	13.94		27.30	26.04	14.07	80.5	25920	8.68	Auxiliary steam included c.n.p.	
7	11150	30.42	26.05	14.49		13.85	13.90		27.22	26.07	14.10	78.3	25830	9.10	Constant nozzle press.	28 = 27−(285−10)
8	10970	29.58	25.51	14.37		13.64	13.70		27.31	26.07	14.15	86.5	27930	8.76	Do	
9	11250	32.42	25.20	14.69		14.23	13.55		27.42	26.04	14.09	79.0	25980	9.03	Do.	
10	12440	29.89	26.01	14.76		13.95	13.36		27.00	26.08	13.88	93.5	30560	8.27	V.n.p.	
11	8990	32.91	25.79	14.89		14.36	13.78		28.29	26.99	15.10	94.5	25820	8.76	C.n.p.	
12	13240	29.15	25.71	14.72		13.90	13.39		26.90	26.46	13.90	76.5	30320	8.25	Do.	
13	10240	33.76	25.52	15.13		14.51	13.99		27.83	26.10	14.41	96.0	30200	9.01	Do.	
14	11480	29.78	28.30	15.17		14.47	14.26		27.02	26.10	14.03	78.6	25000	9.14	V.n.p.	
15	11504	29.06	—	—		—	—		26.97	26.24	14.01	69.0	23060	—	Aux. included c.n.p.	
16	11526	30.22	27.42	15.02		14.64	13.56		27.10	26.12	14.01	82.0	27400	8.93	C.n.p.	
17	11528	30.90	29.70	15.68		15.20	14.32		26.96	26.20	14.01	81.0	29020	9.53	Aux. included v.n.p.	
18	10740	29.26	25.84	14.78		14.41	13.56		27.31	26.30	14.22	98.0	29230	9.06	C.n.p.	
19	14540	28.60	27.05	14.62		14.30	13.58		26.63	26.69	13.80	66.0	26560	9.08	Do.	
20	14365	27.2	28.15	14.47		14.25	13.50		26.60	26.31	13.80	51.0	20050	9.05	V.n.p.	
21	10320	27.97	26.11	14.27		13.70	13.23		27.49	26.50	14.39	85.0	24520	8.52	C.n.p.	
23	13410	32.05	27.70	15.41		15.25	14.47		26.81	26.37	13.80	75.5	29520	9.81	Do.	
24	12927	28.40	26.14	14.22		14.0	14.29		26.82	26.16	13.81	78.5	27180	8.93	Do.	
25	9730	28.81	27.73	14.65		14.53	13.81		27.57	27.07	14.67	101.0	27200	9.33	Do.	
26	11840	29.45	26.71	14.60		14.44	13.42		27.04	26.09	13.96	91.0	24500	9.06	Do.	
21	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**

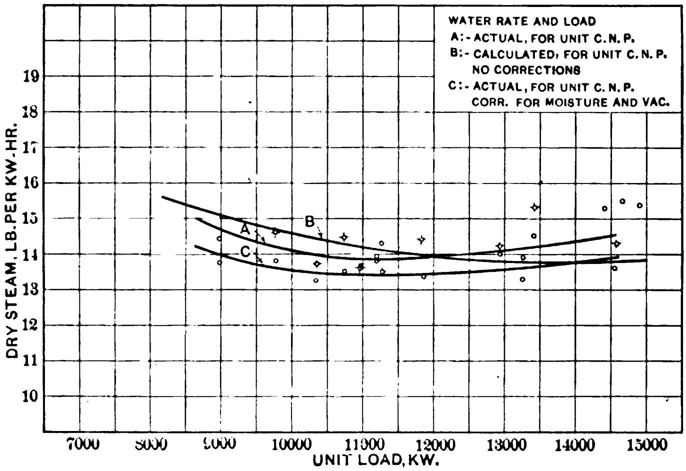


Fig. 11.—Series C

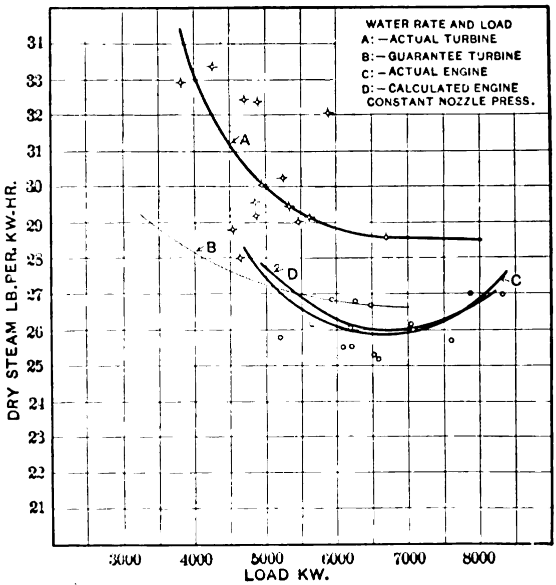


Fig. 11*a*.—Series C

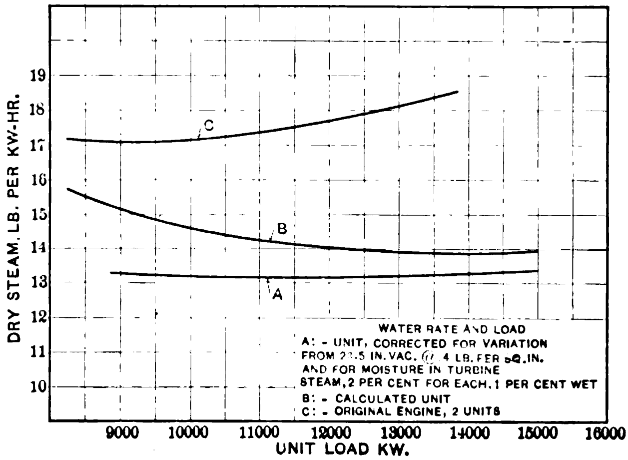


FIG. 11*b*.—Series C

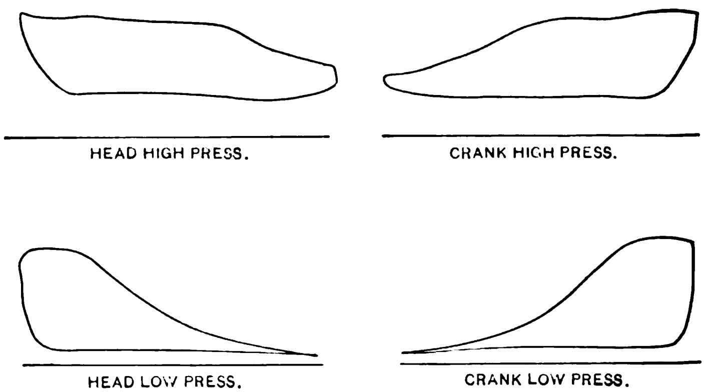


FIG. 12.—Series C

TABLE 7 SERIES D

Test	Duration hr.	Loads: Unit kw.	Loads: Eng. kw.	Loads: Turb. kw.	Pressures: High press. steam lb. per sq. in. abs.	Pressures: Receivers lb. per sq. in. abs.	Pressures: Turb. steam lb. per sq. in. abs.	Pressures: Vacuum lb. per sq. in. abs.	Pressures: Vacuum 29.92 in mercury	Qualities: High press. steam per cent	Qualities: Turb. steam per cent	Water lb. per hr.: Total condensation	Water lb. per hr.: Turb. water	Water lb. per hr.: Total water unit	Dry steam: Turbine	Dry steam: Eng. and unit	Temperatures: Cond. hot well deg. fahr.	Temperatures: Circ. water injection deg. fahr.	Temperatures: Circ. water discharge deg. fahr.
27	6	9567	4875	4683	185.1	64.7	18.14	0.70	28.50	99.0	93.4	8636	133840	142476	125000	141100	78.6	38.80	58.60
28	6	10527	5819	4714	189.8	64.9	16.93	0.87	28.15	99.6	95.2	8570	146730	155300	139700	154700	80.4	39.53	67.04
29	2	11400	6410	5000	184.7	65.2	17.62	1.05	27.87	98.9	97.3	9601	162475	172076	158100	170300	81.3	37.40	67.77
30	4	11365	6590	4810	185.6	64.9	17.62	1.15	27.58	99.0	97.8	10088	161351	171439	157800	169700	84.5	39.20	73.90
31	6	12300	6930	5373	192.0	65.5	17.59	0.90	28.12	99.3	97.8	11006	166826	177832	163200	176800	78.64	36.54	66.00
32	6	13160	7490	5717	193.4	66.3	17.66	0.95	27.98	99.5	97.2	12142	179776	191918	174700	191000	75.34	35.70	69.72
33	4	16085	8505	7670	192.3	65.2	20.00	1.12	27.64	99.8	94.7	7312	247090	254402	234000	254000	86.44	35.05	73.41
34	6	14223	8183	6060	192.3	65.8	17.56	1.11	27.66	99.4	95.7	9361	206261	215622	197500	214300	89.06	34.88	74.30
35	4	13295	7783	5524	194.7	65.8	1713	1.20	27.49	99.5	95.4	11145	187214	198359	178600	197500	90.85	35.22	76.39
36	5	12217	7169	5033	192.7	64.3	16.28	1.05	27.78	99.8	93.8	13017	165908	178925	155500	178700	89.42	34.66	70.76
37	6	10043	5813	4184	190.4	63.9	16.40	1.02	27.84	99.4	93.7	9823	140932	150755	132000	149800	91.80	36.67	70.72

Test	Actual water-rates: Eng.	Actual water-rates: Turb.	Actual water-rates: Unit	Corrected Unit: Moisture	Corrected Unit: Moist. and vac.	I.h.p. engine: High press.	I.h.p. engine: Low press.	Total	factor i.h.p. / kw.
27	28.94	27.65	14.75	14.30	14.30	3861	3502	7363	1.511
28	26.69	30.15	14.68	14.37	14.02	4138	4359	8497	1.461
29	26.57	31.62	14.94	14.74	14.11	4445	4712	9157	1.429
30	25.74	32.81	14.93	14.74	13.82	4477	4727	9204	1.397
31	25.49	30.38	14.36	14.22	13.74	4753	5045	9798	1.414
32	25.50	30.57	14.51	14.29	13.77	5092	5583	10675	1.425
33	29.86	30.50	15.79	15.32	13.46	5902	6229	12131	1.426
34	26.18	32.60	15.07	14.78	13.94	5585	6018	11603	1.417
35	25.38	32.34	14.85	14.56	13.53	5246	5682	10928	1.404
36	24.92	30.91	14.62	14.29	13.57	4873	5421	10294	1.435
37	25.77	31.54	14.93	14.60	13.94	4248	4312	8560	1.473

TABLE 8 SERIES E AND F

No. test	Date 1910	Duration	Loads: Total unit kw.	Loads: Engine kw.	Loads: Turbine kw.	Pressures: Main steam abs. lb. per sq. in.	Main steam gauge lb. per sq. in.	Receivers abs. lb. per sq. in.	Receivers gauge lb. per sq. in.	Low pres. separator abs. lb. per sq. in.	Low pres. sep. gauge lb. per sq. in.	Low pres. sep. unit tube in. mercury	Vacuum Hg Col. in. mercury	Vacuum manom. in mercury abs.	Vacuum abs. lb. abs.	Barometer in mercury	Std. vac. 29.92 Bar. in. mercury	Circ. water pump: Suction in. mercury	Circ. water pump: Discharge gauge lb. per sq. in.
38	Jan. 11	5	16172	8384	7784	197.0	182.3	64.2	49.5	20.60	5.90	10.94	29.30	1.50	0.74	30.63	28.42	12.7	12.0
39	11	5	13485	7798	5895	203.8	189.1	64.5	49.8	16.50	1.80	2.61	29.10	1.58	0.78	30.59	28.34	12.2	12.9
40	12	5	13038	7314	5711	196.1	181.4	63.8	49.1	16.20	1.50	1.82	29.46	1.22	0.60	30.61	28.72	11.0	12.8
41	12	5	12284	6938	5348	200.2	185.5	64.5	49.8	16.10	1.40	2.18	29.32	1.31	0.64	30.57	28.69	12.6	12.1
42	13	5	11252	6248	4938	197.0	182.3	64.0	49.3	16.24	1.54	2.20	29.41	1.32	0.65	30.65	28.60	9.9	14.3
43	13	5	10476	5824	4602	198.0	183.3	63.8	49.1	16.20	1.50	2.00	29.23	1.46	0.72	30.58	28.46	12.6	12.8
44	14	5	9408	4940	4426	198.8	184.1	63.8	49.1	16.10	1.40	2.28	29.47	0.93	0.46	30.31	28.99	9.5	11.6
45	14	1¾	9712	5916	3709	198.2	183.5	64.3	49.6	10.50		−7.48	28.96	1.22	0.60	30.21	28.70	11.6	11.6
46	15	½	12700	7180	5640	198.5	183.8	62.6	47.9	12.96		−2.78	29.45	1.03	0.51	30.32	28.89	13.75	9.5
47	15	½	11940	7060	4780	195.3	180.6	62.6	47.9	12.35		−1.80	29.72	1.03	0.51	30.32	28.89	12.9	9.9
48	15	3	9306	5865	3323	196.3	181.5	63.8	49.1	9.65		−10.49	29.13	1.20	0.59	30.33	28.72	12.0	10.6
								46.3	31.6										
49	15	1	10940	6640	4300	194.9	180.2	49.3	35.6	11.65		−6.62	29.19	1.13	0.56	30.32	28.79	12.1	10.9
50	15	4	15498	8169	7260	192.0	177.3	59.0	44.3	17.80	3.10	3.54	29.23	1.13	0.56	30.32	28.79	14.6	10.4
51	17	3	11240	6753	4376	194.0	179.3	55.0	40.3	11.50		−6.71	29.25	1.19	0.58	30.38	28.73	11.5	9.9
52	17	3	7200	4743	2400	196.5	181.8	41.5	26.8	7.97		−14.92	29.07	1.29	0.63	30.29	28.63	10.6	10.7
53	17	3	11927	7070	4834	199.0	184.3	52.9	38.2	12.75		4.58	29.10	1.25	0.61	30.26	28.67	13.2	10.1
54	26	3	14173	7820	6283	193.4	178.6	55.7	40.9	15.18	0.48	1.04	29.31	0.93	0.46	30.03	28.99	10.1	9.5
55	26	3	8347	5403	2910	197.4	182.7	43.0	28.3	8.21		−13.48	28.90	1.15	0.57	29.97	28.77	12.4	9.0
56	26	3	13033	7457	5550	197.2	182.5	54.3	39.6	14.09		−1.75	29.01	1.01	0.50	29.90	28.91	13.2	9.4
57	27	3	14580	7960	6583	199.7	179.2	59.6	45.1	15.57	0.87	+3.04	28.85	0.85	0.42	29.49	29.07	10.3	8.8
58	27	3	6673	4420	2213	197.7	183.2	40.1	25.6	7.08		−15.14	28.48	0.98	0.48	29.48	28.94	12.6	8.6
59	27	3	10007	6194	3804	199.1	184.6	47.3	32.0	10.35		−8.59	28.55	0.94	0.46	29.50	28.98	14.3	8.7
60	28	3	11820	6923	4860	195.1	180.5	51.6	36.9	12.10		−4.98	28.96	0.87	0.43	29.79	29.05	10.7	10.4
61	28	3	11480	6587	4893	196.8	182.2	51.4	36.7	12.34		−4.46	28.88	1.00	0.49	29.79	28.92	12.4	10.2
62	28	3	15860	8440	7410	195.0	180.4	63.4	48.8	17.84	3.14	7.60	28.73	1.13	0.58	29.79	28.73	13.9	9.9

TABLE 9 SERIES E AND F

		High press throttling calorimeter				No. 1 separating			No. 2 separating			No. 1 throttling				No. 2 throttling		
No. test	Load kw.	Av. main steam temp. deg. fahr.	Cal. discharge temp. deg. fahr.	Cal. discharge press gauge in. mercury	Quality per cent	Moisture lb.	Flow lb.	Quality per cent	Moisture lb.	Flow lb.	Quality per cent	Steam temperature deg. fahr.	Discharge temperature deg. fahr.	Discharge press vacuum in. mercury	Quality per cent	Discharge temperature deg. fahr.	Discharge press vacuum in. mercury	Quality per cent
38	16172	380.6	312.1	18.27	99.5	11.55	153.43	92.9				229.2	198.4	17.76	99.2			
39	13485	383.4	282.0	25.68	97.9	10.49	117.59	91.8				217.6	184.2	20.31	98.8			
40	13038	380.2	302.9	21.81	99.2	10.10	119.41	92.2				216.7	182.0	20.74	98.8			
41	12284	381.9	297.5	19.80	98.9	9.88	119.93	92.4				216.3	180.3	20.55	98.7			
42	11252	380.6	294.8	20.77	98.7	9.73	120.16	92.6	1.42	18.77	93.0	216.7	181.5	20.60	98.7	164.0	26.12	98.1
43	10476	381.0	291.8	20.42	98.5	8.86	111.94	92.6	3.18	46.47	93.6	216.7	182.9	21.50	98.8	168.9	26.23	98.4
44	9408	381.3	297.9	21.78	98.7	8.05	99.50	92.5	1.08	18.90	94.6	216.4	179.3	21.55	98.6	177.0	25.71	98.5
45	9712	381.1	294.8	21.92	98.7	1.10	14.10	92.8	0.79	11.95	93.8	195.4	172.5	23.70	99.2	159.5	27.37	98.6
46	12700	381.2	296.7	21.40	98.8	0.43	10.60	96.1	0.16	4.00	96.2	210.2	170.3	21.30	98.4	163.9	26.40	98.3
47	11940	379.9	304.0	20.63	99.1	0.29	9.10	96.9	0.16	3.60	95.8	203.3	176.0	22.48	98.9	165.7	26.72	98.6
48	9306	380.3	290.5	21.18	98.6	2.43	42.25	94.6	1.22	16.88	93.3	191.8	171.2	24.29	99.3	156.9	27.42	98.6
49	10940	373.7	299.0	21.05	98.9	0.74	16.77	95.7	0.41	6.90	94.4	200.3	178.3	22.62	99.3	167.3	26.76	98.7
50	15498	378.5	305.6	19.77	99.4	2.84	70.70	96.2	1.27	41.56	97.0	221.4	189.4	19.89	98.8	182.9	25.40	98.6
51	11240	379.4	292.6	21.93	98.6	2.04	51.67	96.2	1.15	19.96	94.5	199.8	174.8	22.68	99.0	165.0	27.04	99.1
52	7200	380.4	228.8	20.71	98.4	2.04	36.77	94.7	0.93	14.05	93.7	182.4	163.0	25.21	99.3	148.0	27.75	98.6
53	11927	381.4	294.4	20.64	98.6	1.79	56.20	95.3	1.11	21.66	95.1	204.7	177.0	21.96	99.0	168.8	26.73	98.7
54	14173	379.1	296.9	22.41	98.9	2.13	56.70	96.3				213.3	191.4	19.92	99.4			
55	8347	380.8	292.9	20.87	98.6	1.57	38.91	96.1				184.2	165.2	24.20	99.3			
56	13033	380.7	298.2	20.25	98.7	1.63	61.64	97.4				209.7	184.9	20.81	99.1			
57	14580	379.2	298.8	21.75	99.0	2.06	70.87	97.2				215.3	188.9	18.77	99.0			
58	6673	380.9	298.4	21.80	99.0	1.79	33.30	94.9				178.4	161.1	24.41	99.4			
59	10007	381.5	287.0	21.53	98.2	2.62	47.12	94.7				194.8	171.1	22.70	99.2			
60	11820	379.8	299.9	21.34	99.0	1.56	54.77	97.2				202.4	175.0	21.67	99.0			
61	11480	380.5	302.8	21.00	99.1	1.55	55.79	97.3				203.3	178.4	21.57	99.0			
62	15860	379.7	299.7	20.63	99.0	2.19	80.02	97.3				221.9	197.6	17.87	99.3			

TABLE 10 SERIES E AND F

No. test	Thomas calorimeter: Watt hr.	Thomas calorimeter: Steam temperature, deg. fahr.	Thomas calorimeter: Cal. discharge temperature deg. fahr.	Thomas calorimeter: Cal. discharge water lb.	Thomas calorimeter: Quality per cent	No. 1 Combined quality per cent	No. 2. combined quality per cent	Average quality per cent	Exhaust from engine, Separating cal.: Moisture lb.	Separating cal.: Flow lb.	Separating cal.: Quality per cent.	Throttling cal.: Steam temperature deg. fahr.	Throttling cal.: Cal. discharge temperature deg. fahr.	Throttling cal.: Cal. discharge press. in. mercury	Throttling cal.: Quality per cent	Throttling cal.: Combined quality per cent.	Quality by separator water and turb. steam quality per cent
38	6600	229.2	414.6	93.90	84.1	92.2		90.2									
39	5623	217.6	430.6	84.10	86.3	90.7		89.4									
40	4758	216.7	429.9	93.60	92.4	91.1		91.5									
41	3242	216.3	412.7	70.20	93.2	91.2		91.9									
42	4268	216.7	426.8	110.20	94.4	91.4	91.2	93.0									
43	5000	216.7	408.3	116.50	94.3	91.5	92.1	92.6									
44	4575	216.4	424.6	88.80	91.9	91.2	93.2	92.1									
45	1519	195.4	445.2	30.90	94.9	92.0	92.5	93.1									
46	500	210.2	356.9	20.40	98.5	94.6	94.6	95.9									
47	350	203.3	454.2	27.40	95.6	95.8	94.5	95.3									
48	2100	191.8	420.0	37.92	91.7	93.9	92.0	92.5									
49						95.0	93.2	94.1									
50	2377	221.4	346.5	81.70	95.8	95.0	94.4	95.1									
51	2100	199.8	420.7	47.70	95.4	95.2	93.6	94.7									
52	2300	182.4	395.5	58.40	96.5	94.0	92.4	94.3									
53	2500	204.7	433.2	59.00	96.2	94.3	93.8	94.8									
54	650	213.3	276.7	44.05	98.0	95.7		96.9	2.53	26.90	91.4	213.8	180.5	23.29	98.7	90.2	89.6
55	600	184.2	293.6	28.10	97.4	95.4		96.4	2.05	15.17	88.1	185.6	148.7	26.71	98.5	86.8	90.2
56	600	209.7	268.5	44.40	98.1	96.5		97.3	2.53	21.70	89.5	209.5	167.7	25.41	98.6	88.2	90.3
57	600	215.3	260.8	56.10	98.4	96.2		97.3	1.92	21.40	91.8	216.2	172.1	25.16	98.4	90.3	89.3
58	450	178.4	267.7	24.90	97.0	94.4		95.7	1.88	17.12	90.7	177.9	148.3	25.80	98.8	89.0	89.7
59	600	194.8	265.5	32.80	97.2	94.0		95.6	2.28	15.72	87.3	195.3	154.0	26.02	98.5	86.0	89.8
60	600	202.4	274.2	39.90	98.2	96.3		97.3	2.49	19.17	88.6	203.4	163.4	25.76	98.5	87.3	90.3
61	600	203.3	272.8	41.40	98.3	96.3		97.3	2.34	16.95	87.9	204.1	160.1	26.07	98.3	86.4	91.2
62	700	221.9	274.3	55.40	98.1	96.6		97.4	2.11	24.65	92.1	222.8	178.4	24.73	98.5	90.7	89.8

TABLE 11 SERIES E AND F

Test	West main steam deg. fahr	East main steam deg. fahr.	Average main steam deg. fahr.	West re-ceiver deg. fahr.	East re-ceiver deg. fahr.	Average re-ceiver deg. fahr.	East engine exhaust deg. fahr.	East separator inlet deg. fahr.	Separ-ator outlet deg. fahr.	Turb-ine bowl deg. fahr.	Con-denser deg. fahr.	Hot well water deg. fahr.	Circ. water injection deg. fahr.	Circ. water discharge deg. fahr.
38	381.0	380.2	380.6	297.0	297.4	297.2	230.5	230.1	229.2	228.5	90.90	71.20	37.66	57.28
39	384.1	382.8	383.4	297.3	297.4	297.4	218.7		217.6	217.0	94.60	76.23	39.85	62.51
40	380.3	380.1	380.2	296.1	297.5	296.8	218.0	217.6	216.7	216.1	84.45	70.97	32.03	51.84
41	382.4	381.4	381.9	297.0	297.7	297.3	217.9	217.2	216.3	216.3	87.17	73.41	33.95	56.76
42	380.2	380.9	380.6	296.9	297.0	297.0	218.6	218.6	216.9	216.9	87.18	75.25	31.82	56.67
43	380.6	381.3	381.0	296.8	296.6	296.7	217.9		216.7	216.3	89.32	80.17	32.75	57.14
44	380.3	382.2	381.3	296.9	296.5	296.7	217.6		216.4	216.1	73.87	59.42	31.63	41.98
45	380.3	381.8	381.1	296.8	297.7	297.3	208.2		195.4	196.7	86.72	66.20	32.22	43.97
46	379.7	382.7	381.2	295.0	296.0	295.5	209.0		210.2	208.0	77.20	63.70	40.20	53.10
47	379.0	380.8	379.9	295.3	296.0	295.6	205.0		203.3	204.0	80.00	63.00	36.00	46.85
				297.1	296.4	296.7	193.7			192.5				
48	379.6	381.0	380.3	276.3	275.8	276.1	190.5		191.8	189.4	84.86	60.58	32.90	42.06
49	377.8	381.6	379.7	279.6	280.4	280.0	202.0		200.3	201.0	83.50	62.60	31.38	53.86
50	376.7	380.2	378.5	291.5	291.5	291.5	222.6		221.4	221.0	82.23	65.69	31.51	50.08
51	379.0	379.8	379.4	287.2	286.8	287.0	203.4		199.8	199.8	83.16	65.18	37.50	43.10
52	379.7	381.0	380.4	268.9	270.2	269.6	183.8		182.4	180.8	85.70	58.15	31.47	39.81
53	380.5	382.3	381.4	285.5	283.2	284.4	205.7		204.7	204.6	83.65	65.65	31.46	45.37
54	376.3	381.8	379.1	287.1	288.7	287.9	215.6		213.3	213.3	81.20	57.26	33.54	47.77
55	378.0	383.5	381.8	271.8	271.7	271.7	187.0		184.2	183.8	81.00	58.64	33.08	41.30
56	378.4	383.0	380.7	285.8	286.5	286.2	209.3		209.7	207.6	74.70	60.72	33.40	50.10
57	377.0	381.4	379.2	293.0	291.6	292.3	217.5		214.9	215.5	67.41	53.21	33.28	47.60
58	379.4	382.5	380.9	267.5	267.9	267.7	177.4		177.4	176.3	78.20	53.85	33.18	39.46
59	380.0	383.0	381.5	277.5	277.4	277.5	195.7		194.8	194.1	78.30	59.12	33.40	43.66
60	377.9	381.7	379.8	283.2	283.0	283.1	204.4		202.4	202.4	74.04	59.60	33.25	46.00
61	378.5	382.4	380.5	283.0	282.5	282.8	205.0		203.3	203.2	77.18	61.74	33.06	47.23
62	377.5	381.8	379.7	296.3	296.3	296.3	223.9		221.9	221.8	82.42	62.79	33.64	56.00

TABLE 12 SERIES E AND F

		Water per hour								Water rates					I.h.p.			
No.	Load kw.	Turbine water weighed lb. per hr.	Turbine water venturi lb. per hr.	Sep. and traps weighed lb. per hr.	Sep. water lb. per hr.	Traps Venturi lb. per hr.	Total enclosed water lb. per hr.	Dry steam engine lb. per hr.	Dry steam turbine lb. per hr.	Actual unit lb. per kw-hr.	Actual engine lb. per kw-hr.	Actual turbine lb. per kw-hr.	Corrected unit moisture only lb. per kw-hr.	Corrected unit total corrected lb. per kw-hr.	Average high pressure i.h.p.	Average low pressure i.h.p.	Total i.h.p.	Factor i.h.p. per kw.
38	16172	237480		7425	7175	250	244905	243700	214200	15.07	29.54	27.51	14.40	14.10	5640	6117	11757	1.404
39	13485	187193		9883	5881	4002	197076	193000	167400	14.32	24.76	28.38	13.48	13.10	5104	5847	10951	1.404
40	13038	170661		12271	6281	5980	182932	181500	156200	13.92	24.78	27.35	13.44	13.42	4931	5650	10581	1.447
41	12284	160229		12064	3628	8436	172293	170400	147200	13.88	24.57	27.51	13.39	13.28	4800	5306	10106	1.457
42	11252	147142		10927	2607	8320	158069	156100	136900	13.87	24.99	27,72	13.54	13.42	4250	4330	8580	1.374
43	10476	138766		9939	1801	7138	147153	145000	128500	13.85	24.90	27.91	13.47	13.21	4227	4280	8507	1.460
44	9408	122689		8387	227	8160	131076	129400	113000	13.75	26.19	25.53	13.32	13.59	3771	3490	7261	1.470
45	9712	121870		13160	4910	8250	135030	133300	113500	13.72	22.53	30.59	13.49	13.45	3819	4367	8186	1.385
46	12700	160960		18874	11242	7632	179834	177700	154400	13.99	24.75	27.38	13.62	13.77	4994	6313	11307	1.575
47	11940	142740		17385	8935	8450	160125	158700	136000	13.30	22.49	28.45	13.15	13.31	4675	5736	10411	1.475
48	9306	114372		12555	4744	7811	126927	125100	105800	13.44	21.34	31.84	13.25	13.25	4129	4321	8450	1.441
49	10940	134785		16565	8257	8308	151350	149700	126900	13.69	22.40	29.50	13.39	13.46	5039	4545	9584	1.444
50	15498	202656		19161	16661	2500	221817	220400	192900	14.22	26.99	26.55	13.96	14.03	5784	5825	11609	1.421
51	11240	133462		16689	8399	8290	150151	148100	126500	13.19	21.95	28.89	13.04	13.04	4585	5244	9829	1.456
52	7200	89158		10861	7170	3691	100019	98400	84080	13.67	20.75	35.04	13.52	13.43	3662	3478	7140	1.505
53	11927	143897		17901	8164	9737	161798	159500	136500	13.38	22.57	28.22	13.13	13.08	4995	4897	9892	1.400
54	14173	176565		19180	12930	6250	195745	193600	171050	13.66	24.75	27.22	13.54	13.81	5430	5370	10800	1.400
55	8347	99210		13733	6183	7550	112943	111400	95620	13.34	20.60	32.85	13.23	13.28	3907	3792	7699	1.425
56	13033	158112		18849	11159	7690	176961	174700	153850	13.40	23.43	27.72	13.28	13.47	5115	5120	10235	1.373
57	14580	182508		20011	14741	5270	202599	200700	177600	13.75	25.19	26.95	13.65	14.00	5376	5673	11049	1.388
58	6673	81533		11225	4900	6325	92958	91800	78000	13.76	20.78	35.27	13.65	13.87	3282	3170	6452	1.460
59	10007	120863		14578	6478	8100	135441	133050	115600	13.30	21.48	30.38	13.13	13.39	4452	4294	8746	1.413
60	11820	141930		17833	9873	7960	159763	158200	138100	13.38	22.84	28.41	13.28	13.61	5108	4796	9904	1.431
61	11483	143958		17101	8791	8310	161059	159600	141500	13.92	24.45	24.22	13.75	13.95	4728	4594	9322	1.414
62	15860	206603		19762	15705	4057	226365	224200	201300	14.14	26.58	26.56	13.99	13.99	5750	6538	12288	1.456

TABLE 13 SERIES E AND F

B.t.u. distribution: unit is 1,000,000 B.t.u.

No. test	Total load kw.	Supplied to unit B.t.u.	Supplied to unit per cent	Supplied to turb. only B.t.u.	Supplied to turb. only per cent	Engine kw. output B.t.u.	Engine kw. output per cent	Turb. kw. output B.t.u.	Turb. kw. output per cent	Total kw. output B.t.u.	Total kw. output per cent	To condenser B.t.u.	To condenser per cent	To hot well B.t.u.	To hot well per cent	Lost by radiation etc. B.t.u.	Lost by radiation etc. per cent
38	16172	292.0	100	252.5	86.5	28.61	9.8	26.58	9.1	55.19	18.9	216.6	74.2	9.31	3.2	10.89	3.7
39	13485	232.6		196.6	84.6	26.36	11.3	19.88	8.6	46.27	19.9	168.4	72.4	8.28	3.6	9.64	4.1
40	13038	218.0		182.5	83.7	24.97	11.5	19.49	8.9	44.46	20.4	156.4	71.7	6.65	3.1	10.53	4.8
41	12284	204.7		171.8	83.9	23.67	11.6	18.25	8.9	41.92	20.5	146.9	71.7	6.64	3.2	9.23	4.5
42	11252	187.7		159.5	85.0	21.35	11.4	16.95	9.0	38.37	20.5	136.2	72.5	6.36	3.4	6.85	3.7
43	10476	174.5		149.8	85.9	19.93	11.4	15.76	9.0	35.68	20.5	127.3	73.0	6.69	3.8	4.77	2.7
44	9408	155.8		131.9	84.6	16.87	10.8	15.12	9.7	32.09	20.6	113.4	72.7	3.36	2.2	7.03	4.5
45	9712																
46	12700																
47	11940																
48	9306	150.5		122.3	81.3	20.14	13.4	11.46	7.6	31.61	21.0	107.6	71.5	3.27	2.2	8.06	5.4
49	10940																
50	15498	264.2		224.2	84.8	27.95	10.6	24.85	9.4	52.56	19.9	192.5	72.8	6.83	2.6	12.05	4.6
51	11240	178.0		146.0	81.8	23.16	13.0	15.05	8.4	37.85	21.3	126.5	70.9	4.43	2.5	8.84	5.0
52	7200	118.4		96.41	81.4	16.25	13.7	8.26	7.0	24.37	20.6	85.8	72.5	2.33	2.0	5.74	4.8
53	11927	191.8		157.8	82.3	24.16	12.6	16.53	8.6	40.66	21.2	136.4	71.2	4.84	2.5	9.84	5.1
54	14173	232.4		197.8	83.4	26.76	11.3	21.53	9.1	48.29	20.4	171.8	72.4	4.46	1.9	7.84	3.3
55	8347	133.8		109.55	81.9	18.48	13.8	9.97	7.5	28.45	21.3	97.9	73.2	2.64	2.0	5.77	4.3
56	13033	210.0		175.5	83.6	25.46	12.1	18.97	9.0	44.43	21.2	151.9	72.3	4.54	2.2	9.04	4.3
57	14580	240.7		205.4	85.4	27.20	11.3	22.51	9.4	49.74	20.7	170.9	74.4	3.87	1.6	8.10	3.4
58	6673	110.4		89.25	80.9	15.13	13.7	7.59	6.9	22.73	20.6	79.8	72.4	1.78	1.6	6.02	5.5
59	10007	160.0		133.6	83.2	21.13	13.2	12.99	8.1	34.12	21.3	116.7	72.9	3.28	2.1	5.87	3.7
60	11820	189.8		158.9	83.7	23.67	12.5	16.62	8.8	40.29	21.2	138.4	72.9	3.92	2.1	7.23	3.8
61	11480	191.8		161.5	84.2	22.47	11.7	16.70	8.7	39.17	20.4	140.5	73.3	4.28	2.2	7.83	4.1
62	15860	269.2		232.2	86.3	28.82	10.7	25.31	9.4	54.11	20.1	200.5	74.5	6.36	2.4	8.18	3.0

TABLE 14 SERIES E AND F

No. test	Load unit	Efficiencies: Rankine efficiencies, Engine	Rankine efficiencies, Turb.	Rankine efficiencies, Unit	Thermal effic. ref'd to Rankine, Engine	Thermal effic. ref'd to Rankine, Turb.	Thermal effic. ref'd to Rankine, Unit	Thermal eff. recov. hot well water, Engine	Thermal eff. recov. hot well water, Turb.	Thermal eff. recov. hot well water, Unit	Heat to condenser: Ratio condenser water to steam	B.t.u. per sq. ft. per sec.	B.t.u. per sq. ft. per sec. per deg. rise	Remarks
		Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent				
38	16172	16.7	18.2	30.1	70.3	60.0	65.0	11.7	10.9	19.5	53.5	2.58	0.0594	Constant nozzle pressure auxiliaries exhaust to heaters
39	13485	16.8	16.8	29.1	81.5	63.5	70.5	13.7	10.7	20.5	48.2	1.99	0.0459	" " " " " "
40	13038	17.8	18.4	30.8	76.9	60.0	60.5	13.7	11.0	21.1	52.9	1.86	0.0437	" " " " " "
41	12284	17.6	17.7	30.4	78.5	62.3	69.7	13.8	11.0	21.2	46.4	1.77	0.0428	" " " " " "
42	11252	17.4	17.8	30.3	76.4	61.8	70.1	13.6	11.0	21.2	42.7	1.65	0.0384	" " " " " "
43	10476	17.3	17.7	30.2	78.9	60.5	70.7	13.6	11.4	21.4	44.2	1.53	0.0345	" " " " " "
44	9408	17.6	18.8	29.4	73.2	62.5	71.8	12.9	11.7	21.1	107.7	1.37	0.0369	" " " " " "
48	9306	20.5	15.6	30.5	74.9	61.2	71.0	15.4	9.5	21.7	118.0	1.26	0.0266	Variable nozzle pressure auxiliaries exhaust to heaters
51	11240	19.7	16.4	30.8	76.7	53.6	72.0	15.1	10.5	22.2	150	1.28	0.0298	" " " " " "
54	14173	18.2	18.7	31.2	74.5	59.1	68.1	13.6	11.1	21.2	77.1	2.08	0.0512	" " " " " "
55	8347	21.2	17.5	30.5	74.6	52.6	71.5	15.8	9.2	21.8	11.2	0.92	0.0210	" " " " " "
56	13033	18.2	18.4	31.0	78.5	59.4	69.0	14.2	10.9	21.7	63.4	1.87	0.0566	" " " " " "
57	14580	18.0	19.5	32.2	74.0	57.0	65.4	13.6	11.1	21.0	77.5	2.16	0.0800	" " " " " "
58	6673	21.3	14.6	31.4	73.2	59.0	67.0	15.6	8.6	21.0	15.3	2.55	0.0608	" " " " " "
59	10007	19.5	16.7	31.3	78.5	60.0	69.8	15.3	10.0	21.8	108	1.41	0.0336	" " " " " "
60	11820	19.5	20.2	32.2	74.8	52.9	67.6	14.5	10.7	21.8	82.9	1.67	0.0485	" " " " " "
61	11480	19.6	17.6	31.4	69.8	60.4	66.9	13.7	10.7	21.0	108	2.40	0.0885	Variable nozzle pressure auxiliaries exhaust into separator
62	15860	17.2	18.7	30.0	74.0	59.4	68.9	12.7	11.1	20.7	49.0	2.52	0.0670	" " " " " heaters

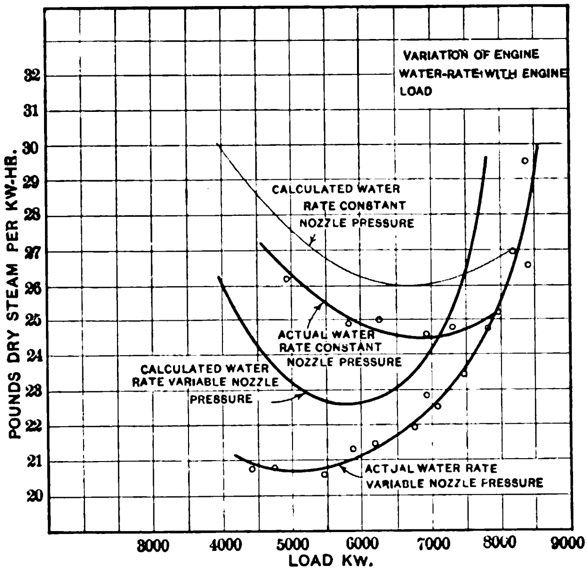


FIG. 13.—Series E and F

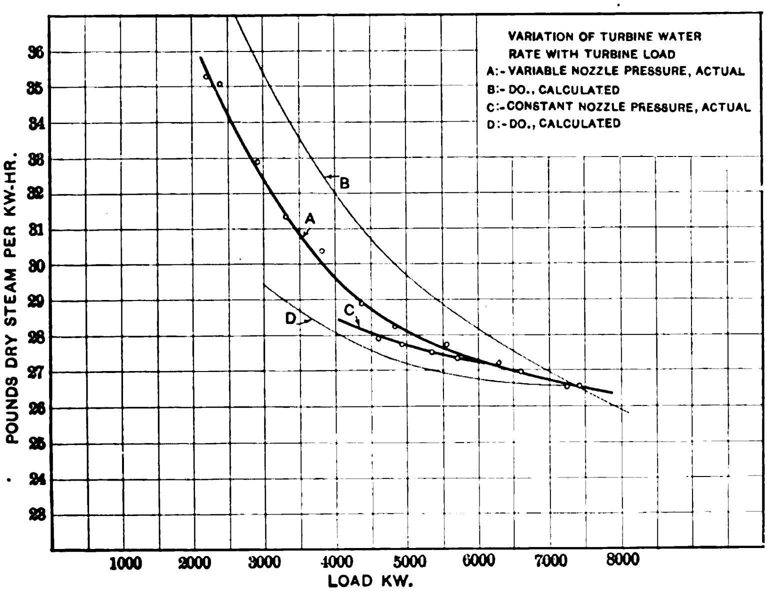


FIG. 14.—Series E and F

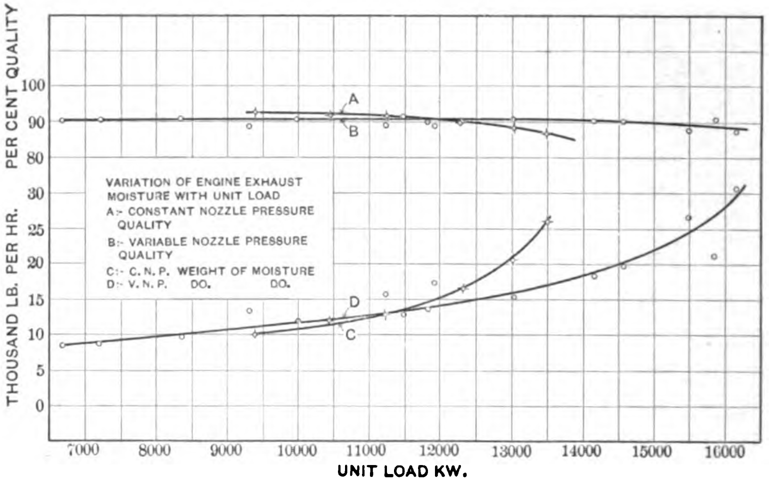


FIG. 15.—Series E and F

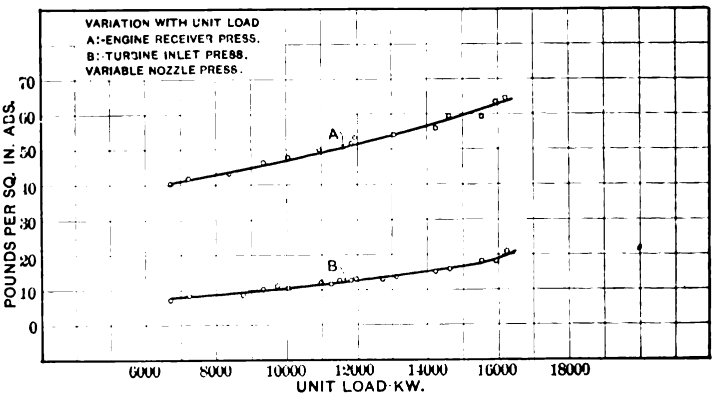


FIG. 16.—Series E and F

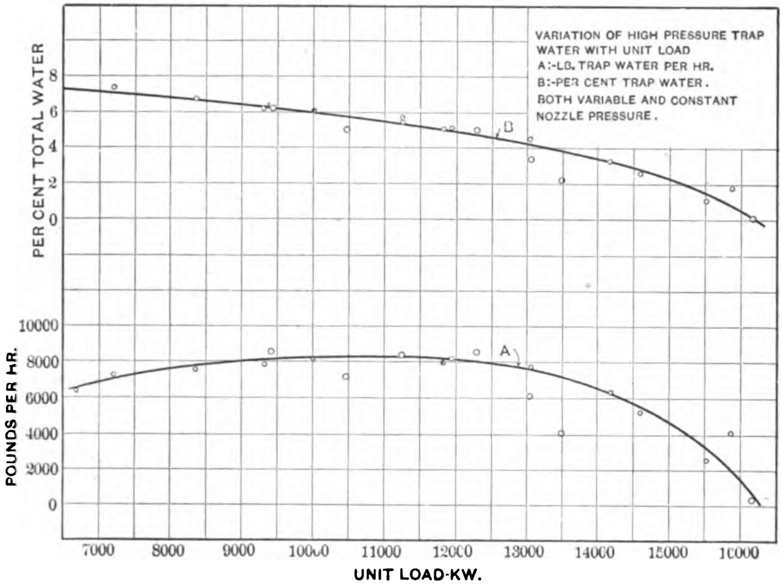


FIG. 17.—Series E and F

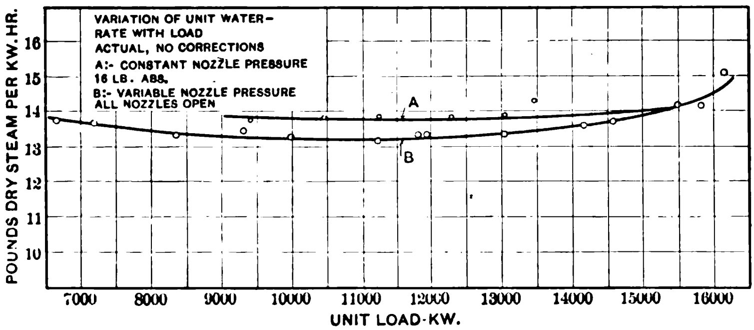


FIG. 18.—Series E and F

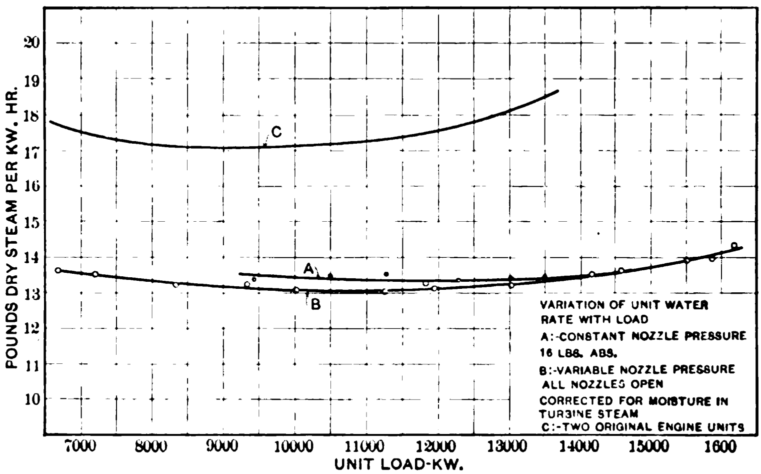


FIG. 19.—Series E and F

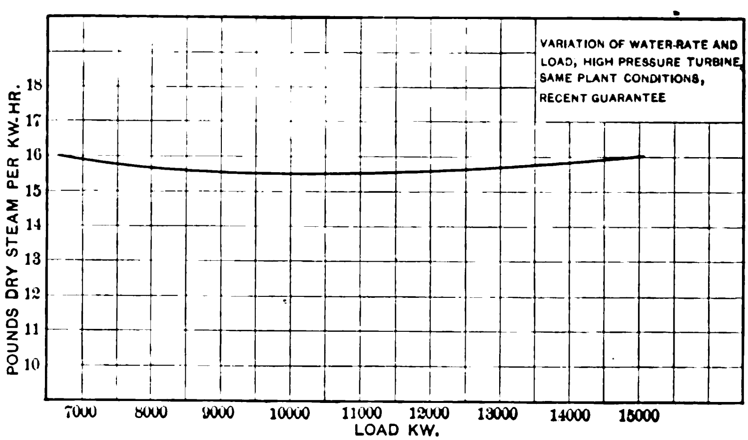


FIG. 19a.—Series E and F

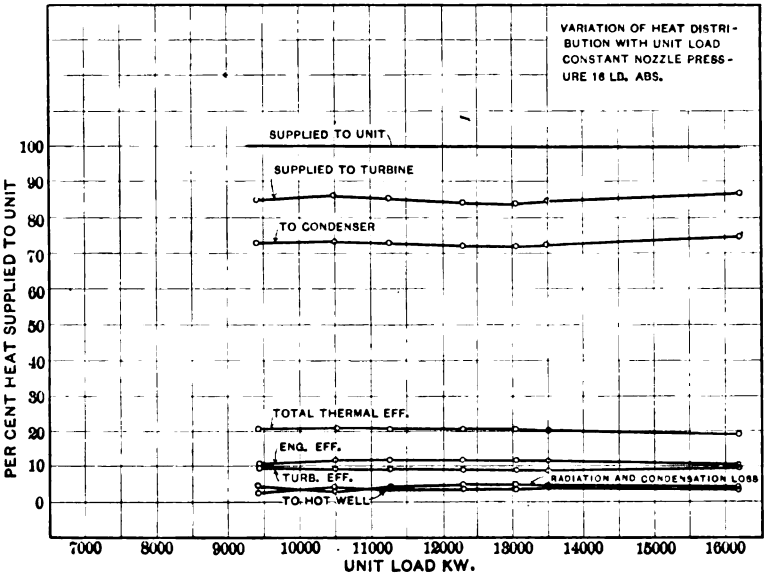


FIG. 20.—Series E

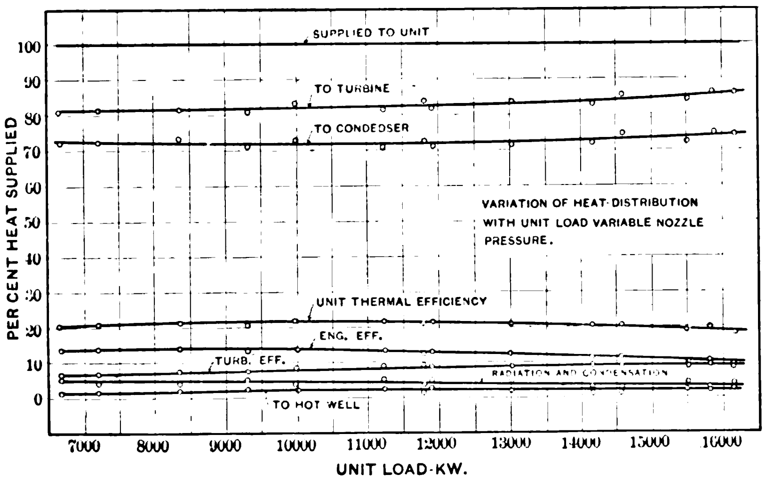


FIG. 21.—Series F

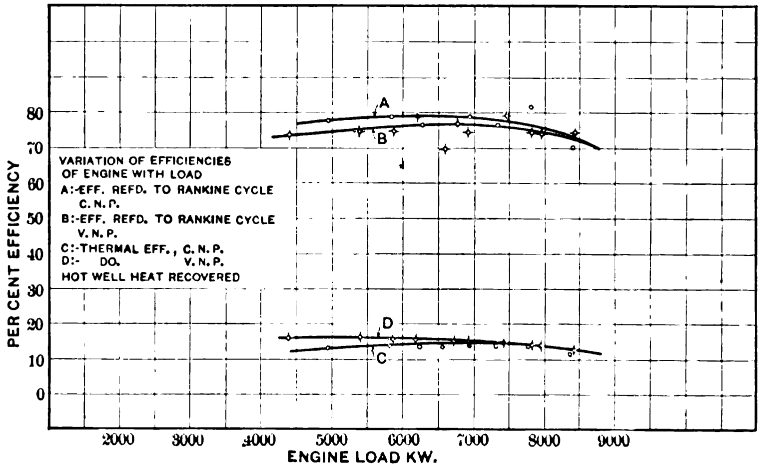


FIG. 22.—Series E and F

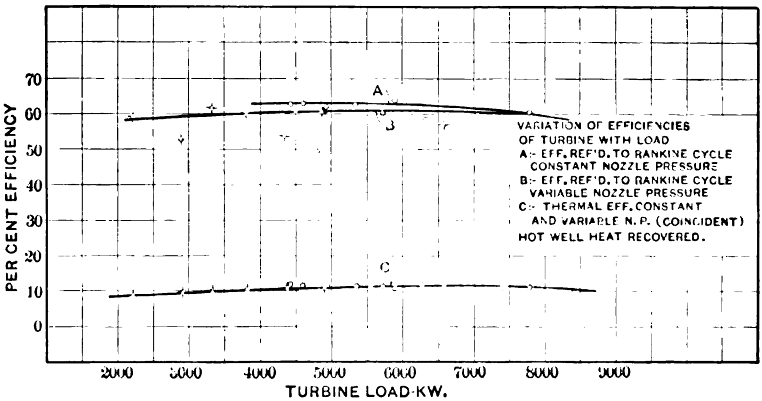


FIG. 23.—Series E and F

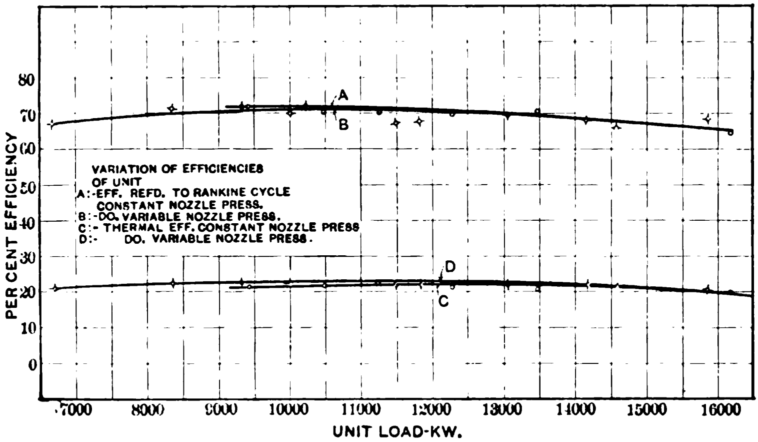


FIG. 24.—Series E and F

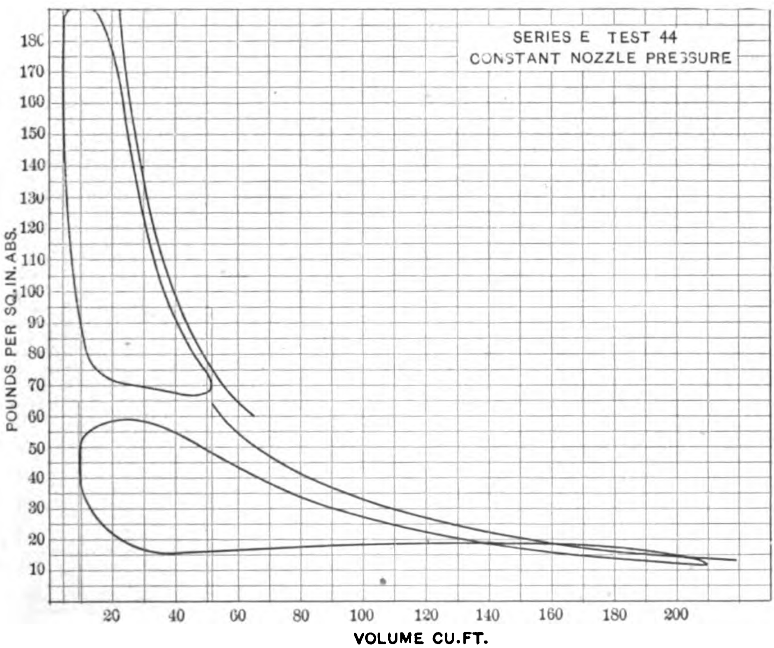


FIG. 25.—Series E, test 44

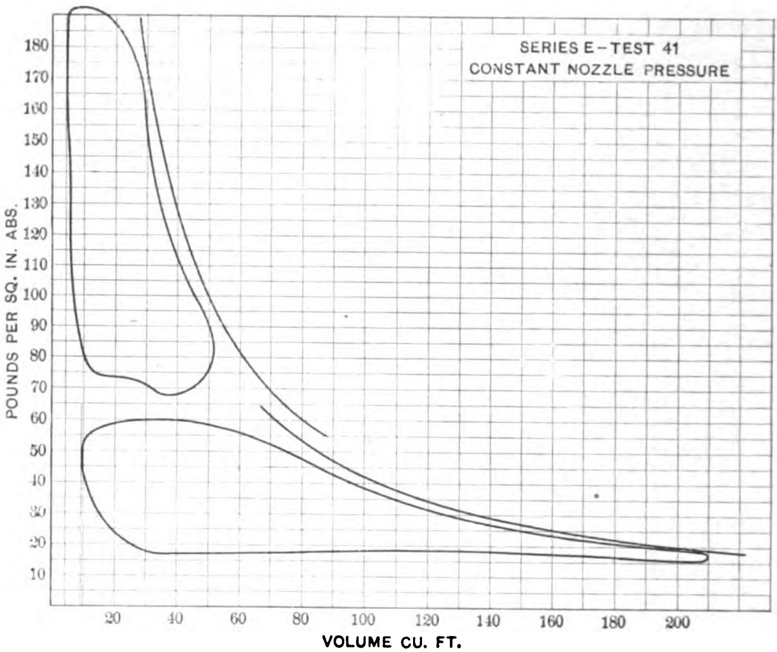


Fig. 26.—Series E, test 41

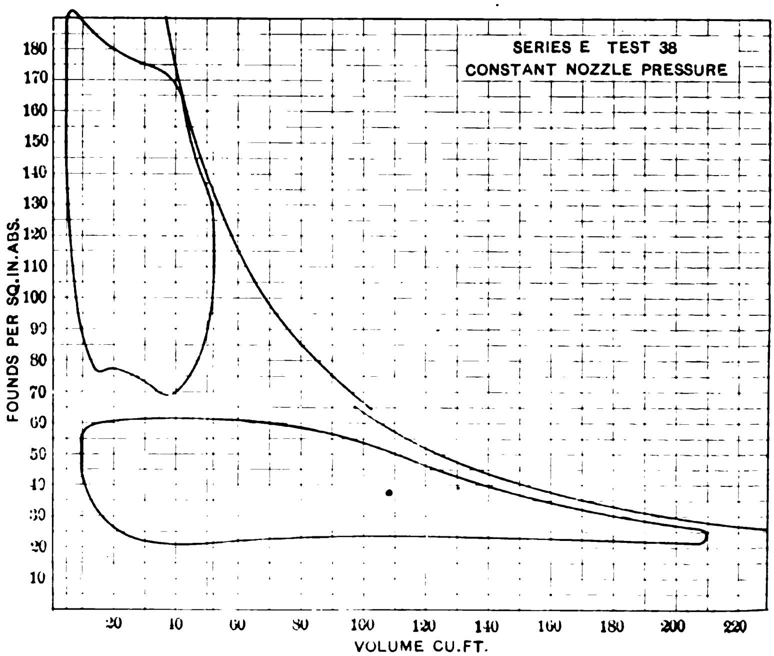


Fig. 27.—Series E, test 38

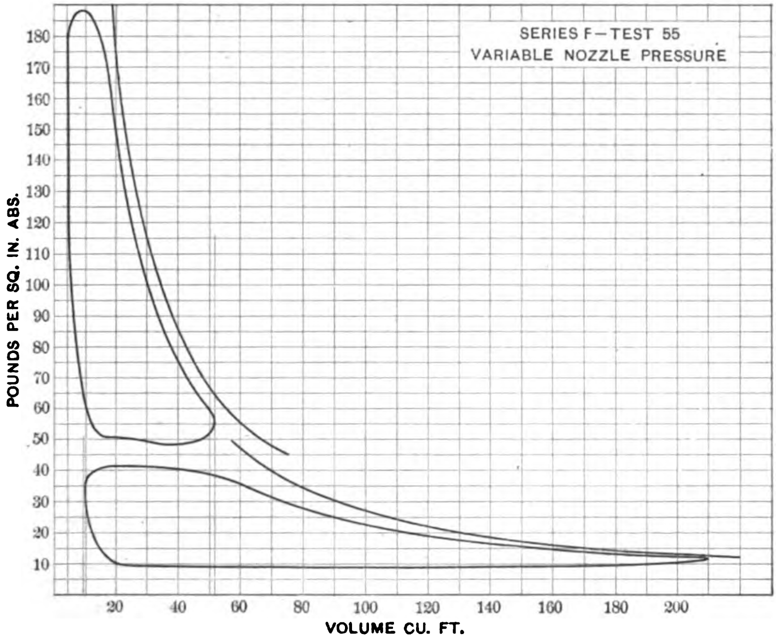


FIG. 28.—Series F, test 55

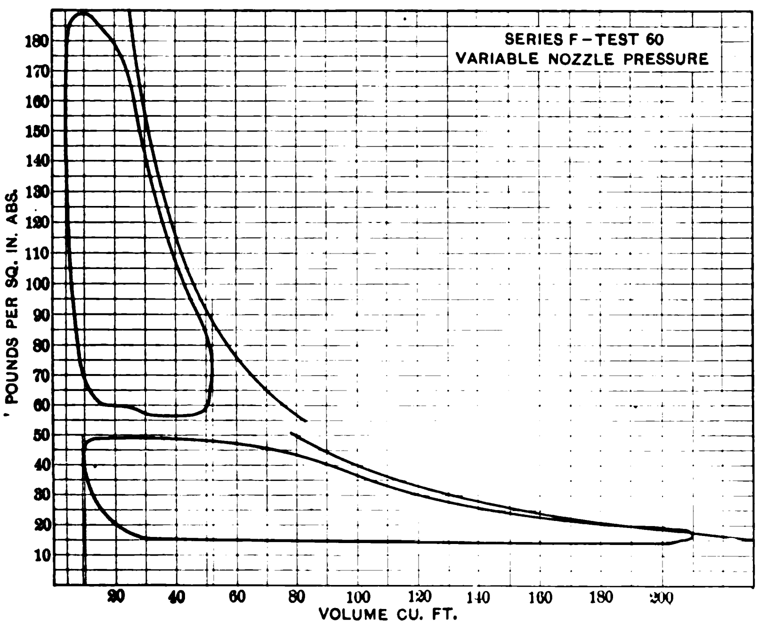


FIG. 29.—Series F, test 60

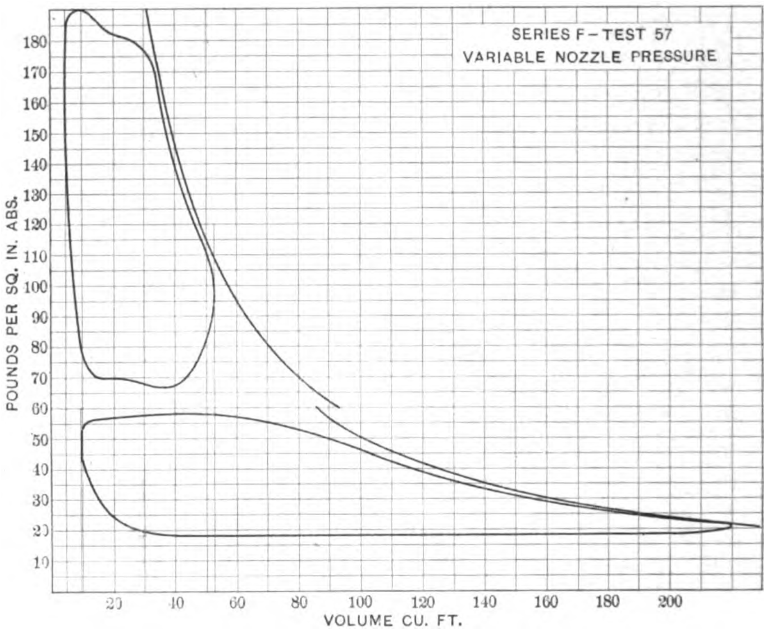


FIG. 30.—Series F, test 57

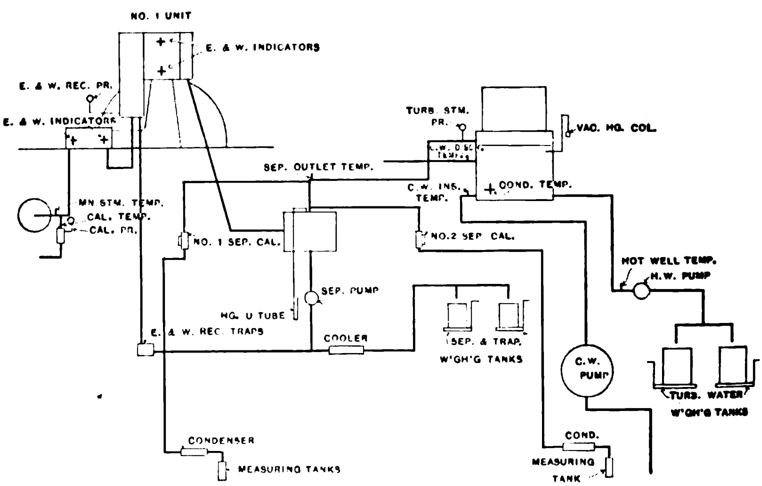


FIG. 31.—Series C, diagramatic test layout

The first point which presents itself in view of the remarkable results of these tests, is the question of accuracy of measurement. The actual unit water-rate is dependent upon three factors only: quality of steam entering the engine, kw. load, and weight of water per hour. The quality of high-pressure steam is easily and accurately determined by means of the ordinary throttling calorimeter. The load on the machines was determined by means of nine integrating meters: two meters each on turbine, engine and total load, connected by the 2-meter method; one balanced 3-phase meter each on turbine, engine, and total load. Each meter was calibrated once a week, and the error was always within one-half of 1 per cent.

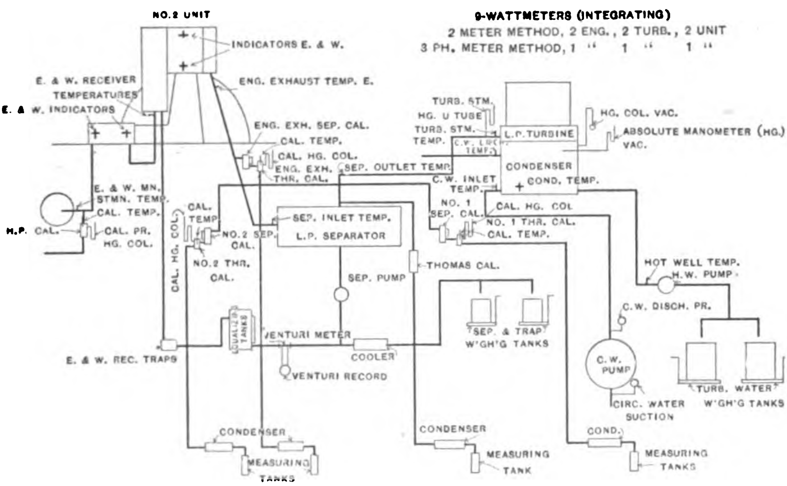


FIG. 32.—Series D, E and F, diagrammatic test layout

The weight of water from the turbine hot-well was determined by a pair of 40,000-lb. standard platform scales, with a recording device in addition to the hand weighing. The load was about 25,000 lb. per scale, the limitation being the size of the tanks on the scales. These scales are graduated to 5 lb. and will balance to 2 or 3 lb., so that the error in reading is negligible. Receiver trap water and low-pressure separator water was weighed together on a pair of 2000-lb. platform scales, reading to $\frac{1}{2}$ lb. All scales were calibrated with standard 50-lb. weights before testing.

The actual trap water weight was obtained by interposing a 1-in. Venturi meter with recording device in the line to the

scales; this was also calibrated by scales and found correct to less than 1 per cent, and the low-pressure separator water obtained by difference.

For examination of thermodynamic conditions within the machines, the most important determination is that of quality of the

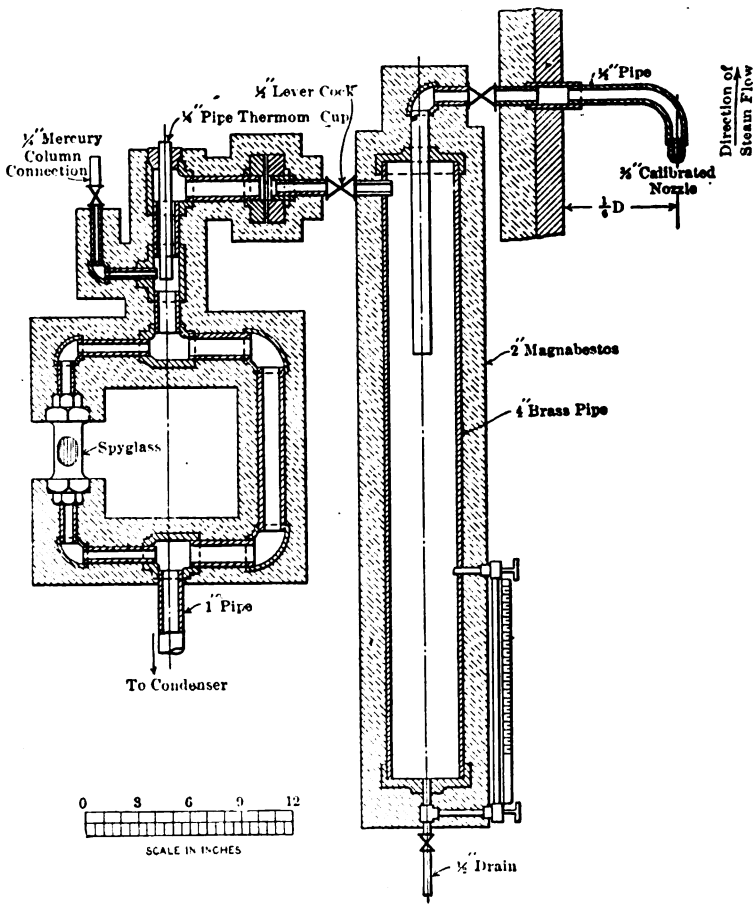


FIG. 33.—Low pressure separating-throttling calorimeter

low-pressure steam to the turbine, since on this depends one of the important corrections to guaranteed conditions. There were no experimental data available that we could discover, bearing on low-pressure quality determinations, so the investigation was made incidental to the tests, from which the following

was established. The ordinary standard perforated pipe sampler is absolutely worthless in giving a true sample, and it is vital that the sample be abstracted from the main without changing its direction or velocity until it is safely in the sample pipe and entirely isolated from the rest of the steam. Multiple orifice nozzles are of no use, as in all cases one orifice will supply practically all the steam, leaving the others useless. After much experimenting with various styles of samples, all of which were failures the single orifice curved tube (Fig. 33) was adopted.

The reason for failure of other styles is plain; if any sudden turn is made by the wet steam in entering the sample nozzle, the entrained moisture, by reason of its immensely greater specific gravity and slight skin friction in the tenuous surrounding fluid, will continue with unchanged direction and a dry sample will enter the nozzle. In other words, the sampler becomes a very fair separator. Again, if the velocity in the sampler is greater than that in the main, even though there be no separating action with the proper sampler, the steam will accelerate into the nozzle, and the moisture will not, giving a dry sample; and the reverse is true if the velocity is less in the sampling nozzle than in the main. The reason this very simple action has not been noted in connection with high-pressure steam is the smaller difference in specific gravity of water and steam, the enormously greater skin friction and the small percentage and highly-divided state of the moisture present.

The successful types of calorimeter for very wet steam were the Thomas electric, and a combination of a separating calorimeter with a throttling calorimeter. By the use of the separating calorimeter most of the moisture was removed, and the small remainder was registered by the throttling calorimeter. At first glance it seems as if, with an initial pressure of 12 lb. to 20 lb. absolute, the throttling calorimeter has no capacity, but by putting a vacuum of 28 in. on the discharge side of the calorimeter, an available heat is obtained sufficient to evaporate 2 or 3 per cent of moisture. When the moisture became less than this, we used the throttling calorimeter direct, eliminating the separating calorimeter altogether. The separating-throttling combination was afterward tested for radiation loss and found to lose less than 0.1 per cent at proper flow. Fig. 33 shows this combination instrument. The large size is necessary on account of the very high specific volume of steam at low pressure.

Referring to Fig. 33, the $\frac{3}{8}$-in. brass nozzle on the sampler is

arranged to point in exactly the opposite direction to the steam flow; the lip of the nozzle is filed to a knife-edge to avoid disturbing the steam current around the sampler mouth by impact and eddies against a sensibly thick lip. The diameter of the brass nozzle is carefully measured and, if necessary, reamed smooth. This form of sampler fulfills the requirements noted above; it takes out the sample without disturbing its direction, by virtue of its position and knife-edged orifice, and the velocity can be kept correct by determining the flow from the following simple formula:

$$w = \frac{Wa}{A}$$

where

w = lb. per hr. flow through calorimeter.
W = lb. per hr. flow through steam main.
a = area of sampler nozzle.
A = area of main.

The sampler is allowed to extend into the pipe one-sixth of the pipe diameter, which has been found to give practically true average flow.

The ½-in. valve at the sampler is opened wide, and the ½-in. lever cock between separating and throttling calorimeters is used to regulate the flow, the throttling action taking place at this point. The rest of the calorimeter is under vacuum, the discharge being connected to a small cooler to condense the steam and then to a volumetric measuring tank. The top of this tank, which is entirely closed except for the pipe connections, was connected with the turbine condenser by a ¼-in. pipe, which gave an available vacuum of over 28 in. without affecting the measuring in any way. The spy-glass is very useful in proving that the calorimeter is working properly, for when the superheat in the throttling calorimeter gets below 6 or 8 deg. it sometimes happens that some moisture goes by, in which case the spy-glass immediately shows it up, no matter how small the quantity. As the spy-glass is most conveniently made of ¾-in. gage glass, more area is required to take away the steam from the calorimeter, and this was done by adding a by-pass of 1-in. pipe around the spy-glass. This allows free flow to take place and does not affect the function of the glass.

The percentage of moisture taken out by the separating portion of the instrument divided by the total percentage of moisture gives the efficiency of the separating calorimeter, which turns out to be much lower than is ordinarily supposed, from 60 to 80 per cent.

For the rest of the measurements steam pressures throughout were taken with high grade thermometers, graduated to 1 deg. and in many cases as low as 0.2 deg., as these are in every case preferable to gages for saturated steam. All pressures below 15 lb. gage and all vacua were measured by mercury column, in addition to temperatures.

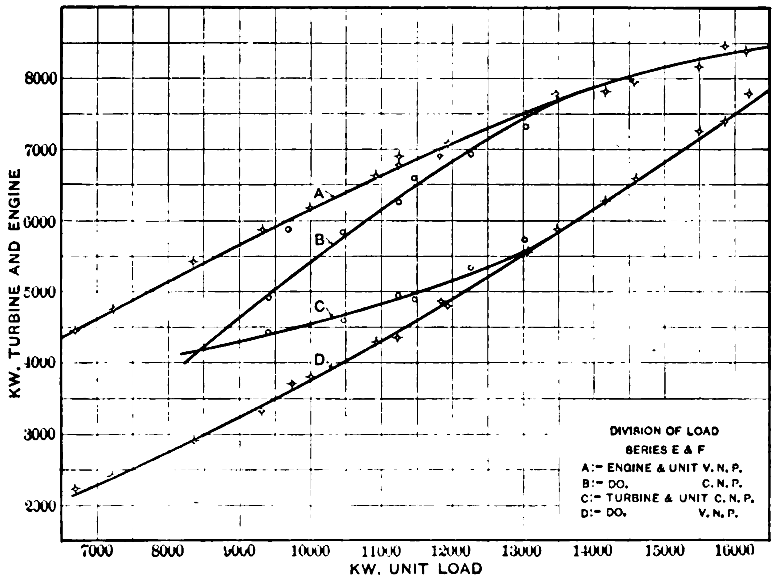


FIG. 34.—Division of load, series E and F

Table 1, Steam to Auxiliaries, includes for tests 25, 22, 24, 21, 23 and 26, the circulating water pump steam only; test 27, circulating water pump and dry vacuum pump; test 29, circulating water pump, dry vacuum pump and boiler feed pump; test 30, boiler feed pump alone.

Fig. 11 and Fig. 11a show variation of points is due to errors in earlier low-pressure calorimetry, before the standard instruments were settled upon.

Table 12, the column of Unit Water-Rate Total Correction, is based on a standard vacuum of 28.72 in. instead of 28.5 in.,

as the higher figure was the average vacuum of the series of tests. Consequently the absolute amount of correction was reduced, which is of course very desirable, in view of the uncertainty of correction factors.

In Fig. 14 these water rates are uncorrected for moisture, etc.

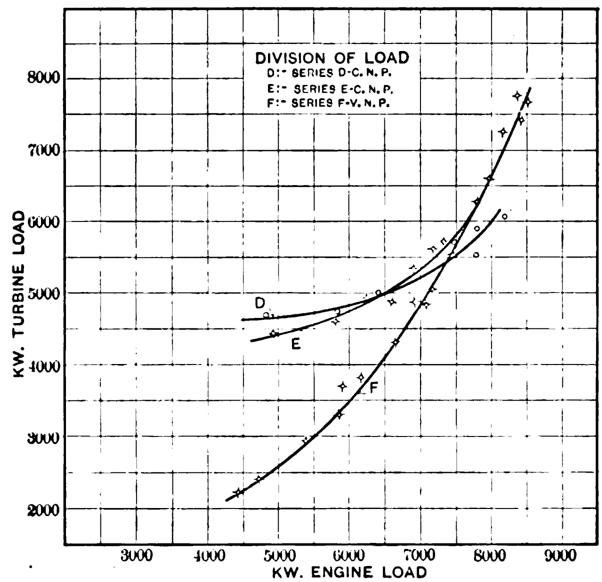


FIG. 35.—Division of load, series D, E and F

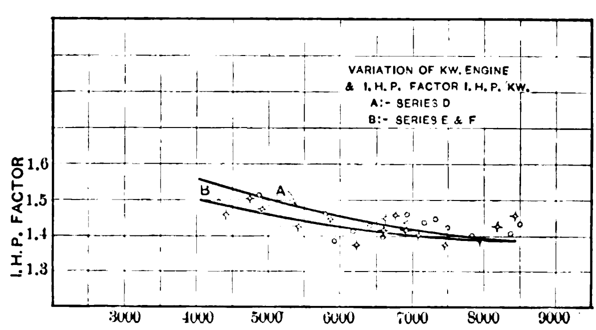


FIG. 36.—Variation of kw-engine and i.h.p. factor

In Fig. 32 the calorimeters were drawn for the sake of clearness, as if they were situated at some distance from the sampling points; actually they were, as in Fig. 1.

Figs. 34 and 35 and 36 serve to show the variation in load between engine and turbine, and the effect of change of efficiency of the two machines.

Formulae and Constants

Engine.

Two high-press. cylinders 42 by 60 in., 9-in. rod
Two low-press. cylinders 86 by 60 in., 10-in. rod.
Rev. per min. 75.
Two 14-in. steam mains.
Two 16-in. high-press. exhausts.
Two 30-in. low-press. exhausts.
Clearances.
High-press. head 9.5 per cent. Crank 10 per cent.
Low-press. head 4.77 per cent. Crank 4.78 per cent.
Average total volume high press. 51.7 cu. ft.
low-press. 209.9 cu. ft.
Average displacement high press. 47 cu. ft.
low press. 200.3 cu. ft.
i.h.p. constant. High press. 15.38. Low press. 65.57 (average)

All combined cards worked out on average basis. Marks and Davis tables used for steam data.

Table II.

E_r = Rankine thermal efficiency, cyclic.
E_t = Engine thermal efficiency.
H_1 = Heat in initial steam at press. p_1 quality x (total per hr.)
H_2 = Heat in steam at p_2, x_2, after adiabatic expansion from p_1, x_1, (total per hr.)

$$\frac{H_1 - H_2}{H_1} = E_r\,E_t = \frac{\text{kw.} \times 3412}{H_1} \qquad \frac{E_t}{E_r} = E_e$$ = engine efficiency referred to rankine cycle.

No heat recovered.

Table III.

p_a, V_a = pressure and volume at high press. cut off, lb. per sq. in. and cu. ft.
p_c, V_c = press. and volume at high press. compression.
W_a = specific density at p_a,
W_c = specific density at p_c.
$V_a W_a - V_c W_c = W$, lb. indicated steam per stroke.

$$\frac{W \times 75 \times 4 \times 60}{\text{i.h.p.}} = \text{indicated water rate (I.W.R.)}$$

I.W.R. $(1+y)$ = A.W.R., (actual water rate)
$y = 1.29\,(r - 1.06)$ kw. $\times 1.465$ = i.h.p.

$$r = \frac{51.7}{V_a} \text{ for high press. cycle = ratio of expansion.}$$

Table IV.

Q_e = Total dry steam per hr. to engine.
Q_f = Trap water per hr.
X_e = low press. exhaust quality.
$(Q_e - Q_f)\ X_e$ = dry steam to turbine, Q_t.

Table VI and VII

X_t = quality of steam to turbine after passing separator.
$1 - X_t = W$, wetness of steam to turbine after passing separator.
K_e = engine kilowatt output.
K_t = turbine kilowatt output.
Q_e = dry steam to unit per hr.

$$\frac{Q_e}{K_e + K_t} = \text{actual water rate } W \text{ for unit.}$$

Q_f = trap water per hr.
Q_s = separator water per hr.
X_1 = high press. quality.

$$\frac{Q_e}{X_1} - Q_s - Q = Q_t'$$

$$Q_t'\ X_t = Q_t$$

$$\frac{Q_t}{K_t} = \text{actual turbine water rate, } W_t$$

$$\frac{Q_e}{K_e} = \text{actual engine water rate, } W_e$$

$$\frac{Q_e}{K_e + K_t\ (1 + W)} = \text{unit water rate, corrected for moisture in turbine steam, } W'$$

$W' - (28.5 - p'_3) = W''$ total corrected unit water rate.
p'_3 = actual vacuum obtained, in mercury.

Tables IX and X.

All throttling calorimeters.

$$X_1 = \frac{H_2 + K\ (T - t_2) - Q}{L}$$

H_2 = total heat per lb. saturated steam at p_2, calorimeter discharge press.
X_1 = quality.
K = separator heat superheated steam at p_2, T.
T = temperature superheated steam in calorimeter.

All separating calorimeters.

$$X_2 = \frac{W_f}{W_m + W_f}$$

t_2 = temperature saturated steam at p_2.
Q = heat per lb. of the liquid.
L = latent heat vaporization per lb. at p_1.

W_m = moisture.
W_f = flow.
All combustion separator-throttle calorimeters.
$X_1\,X_2 = X_1$ combined quality.
Thomas electric calorimeter.

$$\frac{\frac{3.412E}{W} - K\,(T-t)}{L} = 1 - X$$

E = watt-hr. input.
W = lb. steam flow.
K = as above.
T = as above
t = saturated steam temperature at p.
L = latent heat per lb. at p.
X = as above.

Table XII, see VI, VII.
Tables XIII, XIV.

$$E_t = \frac{\text{kw. } 3412}{H_1} \text{ for engine turbine or unit.}$$

$$E_t' = \frac{\text{kw. } 3412}{H_1 - Q} \text{ for unit and turbine only.}$$

E_t = thermal efficiency no heat recovered.
E_t' = thermal efficiency hot well heat recovered.

Discussion on "Test of a 15,000-kw. Steam-Engine-Turbine Unit", New York, March 8, 1910

(Subject to final revision for the Transactions.)

W. L. R. Emmet: While some few applications of low-pressure turbines in connection with electric-generating engines have been put into operation before that which is described in this paper, such cases are relatively unimportant and I think that in all of them the application has been made to a station which was formerly operated non-condensing.

In recent years the science of steam engineering has advanced very rapidly and as the cost of fuel has increased the cost of apparatus has diminished so that we now find ourselves in a position where the question of investment is of much less relative importance than formerly, the value of the product being so very large in proportion to the cost of the apparatus required. For this reason we generally cannot afford to use any apparatus but the best, no matter how great its cost.

The operation of stations by turbines alone is simpler and generally more economical than that of stations which use reciprocating engines and there are many cases where it might be better to install high-pressure turbines instead of coupling low-pressure turbines with existing reciprocating engines. The results shown by Mr. Stott's paper, however, should demonstrate to many station managers that they cannot afford to run reciprocating engines alone when such an improvement can be accomplished by the addition of low-pressure turbines. I regret that Mr. Stott has not dwelt at more length upon the saving in investment and operation which has been effected by this installation, although his tests and explanations afford most of the data necessary for such comparisons. The increase of firing capacity due to the changes made in many of the boilers sometime ago has greatly contributed to the comparisons of the remarkable improvement accomplished. Comparisons of the original conditions in this plant with the ultimate development of the present plan afford a very striking example of what can sometimes be done with an old station.

The results in steam consumption shown by Mr. Stott's tests are very decidedly better than the best results which have ever been accomplished with turbines alone, the advantage in water rate amounting to about 2 lb. per kw-hr. as compared with the best turbine results. It is possible that this station will never produce power more cheaply than the best modern turbine stations are now doing with equal fuel, but the difference cannot be great and when the enormous investment saving is considered, the great value of this change will be apparent.

Some of these curves given in the paper would seem to indicate that the results accomplished by the turbines were inferior to those guaranteed or expected, whereas in fact all guarantees and expectations have been rather exceeded. The reason for this

apparent discrepancy is that Mr. Stott has not made allowance for the losses introduced by the presence of moisture in steam entering the turbines, whereas the guarantees on the turbines were based upon dry steam. Mr. Stott has reported the facts as they exist and as they are influenced by such methods of moisture separation as he has used. If the separation were more perfect the turbine results as shown by the curves would be much better and it is probable that with more experience, an almost complete absence of moisture in the steam turbine can be provided for. In Schenectady, where we are operating two large low-pressure turbines on exhaust steam from a reciprocating engine plant, we are running with steam which is almost completely dry. The reason for this is that the steam has to pass horizontally through a long pipe which ends in a separator and is drained before it reaches the separator. This arrangement gives the steam ample time to throw down its moisture and the last vestige of it is taken by the separator. In most applications of low-pressure turbines and engines, such an arrangement can be provided for, while in the installation referred to in this paper the delivery of steam from engine to turbine is in a downward direction and through very short pipes in which little separation or collection of moisture into drops can occur.

Max Rotter: The success of an enterprise of such magnitude and novelty required, on the part of those responsible for it, a very considerable courage and confidence in engineering calculations. The test results and Mr. Stott's deduction from them will exercise no small influence on all who are interested in the production of power on a larger scale.

One matter of practical interest is the elimination of the moisture and oil from the steam during its passage from the engine exhaust to the turbine inlet. Tests 45 to 62 seem to show that the moisture remaining in the steam, as it entered the turbine, amounted to an average of over 4 per cent. Can it be assumed that this may, without re-heating or increased pressure drop, be reduced to zero. If not, then the inefficiency of the separation must be considered as one of the losses inevitable in an installation of this kind, and corrections for moisture entering the turbine should properly be omitted, as such losses would be on a par with the losses in the low-pressure stages of a high-pressure turbine, due to the water of liquefaction delivered to them from the high-pressure stages. It is not the same as a correction for moisture in the steam as originally delivered to the engine, for the engine and low-pressure turbine, with their necessary connecting elements, must be considered as a single unit and it is proper to correct only for conditions due to the imperfection of external apparatus serving the unit. For instance, while a correction for moisture in the steam would be made in testing an engine as a unital piece of apparatus, no such correction would be made in testing, as a unit, the complete plant of such engine and its boilers. The correction of 1 per cent in

consumption per 1 per cent of moisture delivered to the turbine is the usual full allowance for the internal losses caused by such moisture; as obviously no deduction of the moisture itself can be made, this having been already allowed for in determining the dry steam delivered to the engine. This correction of 1 per cent is thus equivalent to the customary correction of 2 per cent in consumption per 1 per cent of moisture, as applied to a high-pressure turbine performance. The elimination of oil is probably more important as affecting the maintenance of the efficiency of the turbine and surface condenser than that of the boilers.

One of the most interesting features of the paper is the comparison of this engine and low-pressure turbine installation with an installation of high-pressure turbines. It is not clear whether the high-pressure turbine referred to by Mr. Stott is one of a capacity equivalent to that of the low-pressure turbine only, or to that of the combined engine and low-pressure turbine unit. The latter would certainly be proper and seems to be that considered by Mr. Stott in his statements regarding relative costs; but the high-pressure turbine efficiencies shown in Fig. 19*a*, Series E and F, are apparently those of a considerably smaller machine. Nor is it quite proper to compare the efficiencies of two units on the basis of the test performance of one as against the guaranteed efficiencies of the other. A business man will not guarantee more than necessary, nor will he guarantee under any circumstances the best he can hope to do under test. Furthermore, a slight change in operating conditions might materially affect such a comparison. For instance, the majority of modern high-pressure turbine plants operate with some superheat, of which the high-pressure turbine can take greater advantage than can the engine and low-pressure turbine unit. The frequency of the turbo-alternator, in so far as it determines the speed of the turbine, will also exercise some influence upon the results. At 59th Street the slow speed of 750 rev. per min. is somewhat unfavorable to the turbine. A higher turbine speed would, in the case of the engine and low-pressure turbine unit, increase the efficiency of the turbine only; that is, the improvement in efficiency would apply to only about one-half of the total load of the unit; whereas, in the case of a high-pressure turbine of a capacity equivalent to that of the combined unit, the improvement in efficiency would apply to the full output of the machine. The comparative operating expenses must also be considered, and these are unquestionably lower for the high-pressure turbine than for the combined unit.

For the purpose of comparing the steam consumptions of the two types of apparatus, the final results gvien in Table 12, Series E and F, have been replotted herewith on Fig. 1 and curve A drawn through the points. This curve therefore shows the steam consumption of the combined unit, corrected to dry saturated steam at the engine throttle at 180 lb. gage, dry satu-

rated steam at the low-pressure turbine throttle at variable pressure, and a vacuum equivalent to 28½ in. referred to a 29.92-in. barometer. Curve B refers to a high-pressure turbine unit operating with dry saturated steam at 180 lb. gage and a vacuum of 28½ in. referred to a 29.92-in. barometer, at a speed of 750 rev. per min., and having a capacity about equivalent to that of the combined engine-low-pressure-turbine unit. This latter curve shows the steam consumptions it would be perfectly safe to expect from such unit under test, and it is probable that a consumption 0.3 to 0.4 of a pound lower would be attained. In making guarantees, from 1 to 1½ lb. per kw-hr. would be added. A comparison of these curves would indicate that the average difference of 8 per cent as given by Mr. Stott is ample, and 13 per cent as given by him too high.

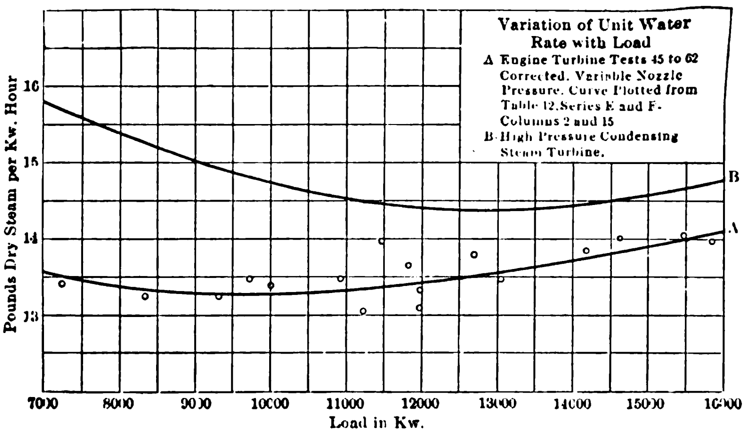


FIG. 1.—Results in Table 12, series E and F

To indicate the effect of a change in operating conditions, curves A and B (Fig. 2 herewith) have been plotted to show the performance of the units when operating under the conditions above mentioned, except that the steam is superheated 100 deg. fahr. It will be noted that the advantage of the combination as against the single unit is materially lowered.

That the high-pressure turbine consumptions, as shown by the curves, are reasonable is proved by a recent unassailable test of this type of turbine, with steam at 180 lb. gage, superheated 100 deg. fahr., and a vacuum of 28¼ in. referred to a 29.92-in. barometer, which showed a consumption of 14.02 lb. per kw-hr.; the turbine having a normal capacity of only 4000 kw. at 1800 rev. per min.

An improvement in efficiency of 13 per cent in the 59th Street plant would almost seem to warrant a combined engine and low-pressure turbine unit as an initial installation, and it would be

interesting to learn whether Mr. Stott would consider such an installation for extensions of this plant beyond the capacity obtainable by adding low-pressure turbines to all of the existing engines.

The conditions for which low-pressure turbines are being considered have multiplied much faster than anticipated. For instance it has been proposed to operate a turbine by means of steam from natural geysers, which is perfectly feasible. The steam would be obtained by passing the hot water through vessels in which a pressure drop would take place and part of the water be evaporated. With such an arrangement it would be necessary to handle 30 to 50 lb. of water to obtain 1 lb. of steam at a pressure slightly below atmosphere.

Another use for low-pressure turbines is that of generating

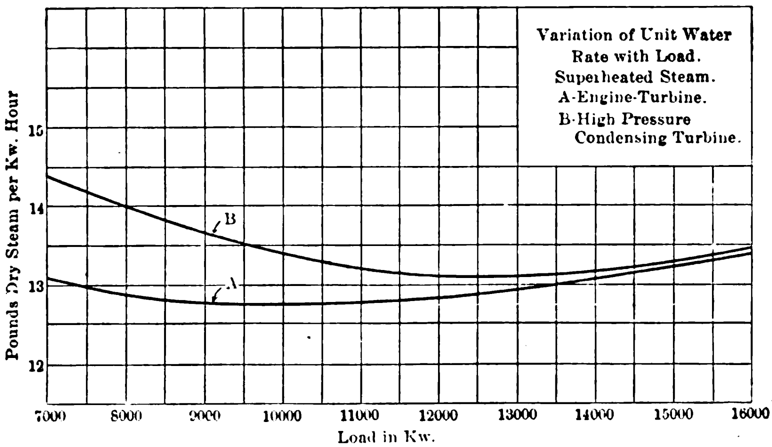


FIG. 2.—Curves A and B, showing performances of units when operating under given conditions

power from hitherto wasted industrial steam. For instance, a turbine is now being installed in an automobile tire factory where the retorts used for vulcanizing are filled with high-pressure steam for a certain period, the major portion of this steam being then blown out into the air before the retorts are opened for recharging. This steam will henceforth be collected in a receiver, in which its pressure will drop approximately to atmospheric, and from which it will be delivered to a low-pressure turbine for use. The supply of steam is almost constant and will generate 1000 to 1200 kw., the only cost being the fixed charges, labor, and the water required for condensing.

Every improved method or appliance is exposed to the danger of being retarded in the progress it really merits by a few ill-advised applications, and there are conditions under which it

would be better not to advocate low-pressure turbines as additions to reciprocating engines. In almost all instances figures will show a saving of steam as achievable by such combination, but the cost of power production in a great many industrial plants is so small an item compared with the other expenses, that a reduction of even 25 per cent in fuel consumption is frequently insignificant when weighed against other considerations.

A low-pressure turbine should not be installed where its steam supply depends upon an old and unreliably decrepit engine. The proper thing here is an independent high-pressure condensing turbine. And as a high-pressure condensing turbine of the same capacity as the engine and low-pressure turbine combined will give so nearly the same efficiency as the combination, the boilers and the condensing apparatus will cost about the same for either installation, the fuel consumption will be about the same, and the engine can be set aside for emergency use.

There are numerous instances where compound engines are not overloaded but underloaded. Many of them are running non-condensing and it is a condenser and not a low-pressure turbine that is needed. The beneficial effect of adding a condenser to an underloaded compound engine is twofold; firstly, it will lower the mean effective pressure at which the engine attains its best efficiency and, therefore, if the engine is underloaded, it will bring the point of best efficiency nearer the running load; and secondly, there is the increased efficiency directly due to condensing.

The installation of a low-pressure turbine may also be a doubtful expedient in a plant which is being electrified and in which the engine is belted or coupled to a lineshaft so that the direct load is decreasing while the electric load is increasing. Of course a generator could be added to the engine, and a low-pressure turbine run in connection with this; but beyond the combined capacity of these it would become absolutely necessary to install a new unit. Under such circumstances the best course would be the installation of a high pressure condensing turbine to start with.

E. F. Miller: I recently made some calculations upon the economy of the low-pressure turbine and found in figuring over some of the tests quoted an apparent efficiency of 76 to 80 per cent of that obtained from the non-conducting engine. I also worked up the efficiencies and steam consumption of the Rankine engine using dry steam at a pressure of 15.6 lb. and exhausting at 28-in. vacuum. The same calculations were made at other pressures down to about 6 lb., as shown in Table 1. Taking the efficiency of the generator as 83 per cent and the mechanical efficiency of the engine as 90 per cent, the steam consumption per kw-hr. was obtained.

Assuming the ratio of efficiency of the low-pressure turbine to that of the non-conducting engine as 63, 67.5 and 72 per cent,

the steam consumptions per kw-hr. were calculated. Table 1 affords a simple means by which steam consumptions may be compared.

TABLE 1 STEAM CONSUMPTIONS OF LOW-PRESSURE TURBINES AT VARYING PRESSURES

Abs. press. at entrance	Temp. at entrance deg. fahr.	Abs. press. at exit	Temp. at exit deg. fahr.	Quality of steam at entrance	Quality of steam at exit	Thermal Eff. of Non-cond. eng. %
15.60	215	1.005	102	1.000	0.8785	15.93
14.13	210	1.005	102	1.000	0.8827	15.38
11.53	200	1.005	102	1.000	0.8916	14.23
9.34	190	1.005	102	1.000	0.9007	13.03
7.51	180	1.005	102	1.000	0.9125	11.75
5.99	170	1.005	102	1.000	0.9203	10.48

Steam per h.p.-hr. of non-cond. eng. per cent	Steam per kw-hr. of non-cond. eng. calling mechanical eff. of eng. 90 per cent and eff. of generator 93 per cent	Steam consumption per kw-hr. of low-press. turbine assuming ratio of act. eff. to that of non-conducting eng. as 63, 67.5 and 72 per cent		
14.72	23.55	33.6	31.4	29.4
15.23	24.36	34.8	32.5	30.4
16.50	26.40	37.7	35.2	33.0
18.09	28.94	40.1	38.6	36.2
20.13	32.20	46.0	42.9	40.3
32.66	36.26	51.8	48.3	45.3

Edward L. Clark: A number of cases have arisen where mills driven mechanically have desired to increase their power by the use of low-pressure turbines. The introduction of the low-pressure turbine in such places is accomplished in a novel and effective manner by tying the electric load and the mechanical load together by means of a synchronous motor or generator. The synchronous motor may either be belted or coupled-direct to the main line shaft driven by the engine, and then electrically interlocked with the generator connected with the low-pressure turbine. With this method, the low-pressure turbine requires no governor and merely delivers power in proportion to the quantity of steam exhausted by the engine.

It is important in the selection of a low-pressure turbine that it should be capable of utilizing the entire engine exhaust. In this arrangement, the turbine may be regarded as the low-pressure cylinder of a triple-expansion engine, and manifestly a proper ratio between the low-pressure turbine and engine cylinders should be chosen. If this feature is not observed, the expansion of the steam will not be efficiently carried out or there

will be free escape of a part of the steam through the relief valve between the engine and turbine. However, a properly selected turbine will pick up the electrical load and the surplus power that it is delivering will go through the synchronous motor, thereby lightening the load of the engine. When the engine is thus relieved of a portion of its load, it naturally gives less steam to the turbine until the whole system automatically balances between the mechanical load and the electric load.

An important feature of operating the low-pressure turbine without a governor is that vacuum comes back on the engine at all loads, the amount of this vacuum being proportional to the amount of load carried by the turbine. By thus varying the inlet pressures on the turbine and maintaining them below atmospheric pressure, looping of the low-pressure card on the engine at light loads is avoided and the low-pressure valves operate smoothly and without noise at all loads. At the same time, both the engine and turbine run in combination at maximum efficiency through their entire range, and the curves obtained are about as straight as the one in Mr. Stott's test.

It will be seen that the flexibility of such an outfit is independent of the mechanical load and the turbine can accomplish practically anything that a high-pressure turbine can accomplish. The gain in power with the synchronous motor system amounts to nearly 100 per cent, due to the fact that the increased rating of the non-condensing engine over what it is at best economy condensing is approximately 20 per cent, which should be added to the 80 per cent additional power given by the low-pressure turbine.

Assuming that an engine running under 125 to 130 lb. pressure consumes per indicated horse power 15 lb. steam-condensing and 21 lb. non-condensing, if we divide the additional steam required when running non-condensing by the kilowatts obtained from a low-pressure turbine, we obtain a kilowatt for very close to 12 lb. additional steam per kw-hr. This must compare with a water rate of say 20 lb. on a high-pressure turbine under the same steam conditions.

An interesting point is that the economies obtained for the combined engine and turbine would be equivalent to a consumption of about 11 to 11½ lb. per indicated horse power in steam engine practice, so that we better the engine economy over what it is at its best point when run condensing, besides producing a kilowatt for less steam than in a high-pressure unit.

In the majority of cases the low-pressure turbines have been installed in plants having from 125 to 140 lb. of steam, and the relative gain is just as marked as in the stations carrying 195 lb. of steam and high degrees of superheat.

E. D. Dreyfus: It is interesting to note the remarkable difference in Rankine cycle efficiency between the engines and the low-pressure turbines. This looks as if there is some opportunity for improvement on the low-pressure turbine. Mr. Flanders

of East Pittsburg, has made quite a study of turbine efficiencies, and has found that a high-pressure complete expansion turbine operating with 175-lb. steam pressure and 100-deg. superheat

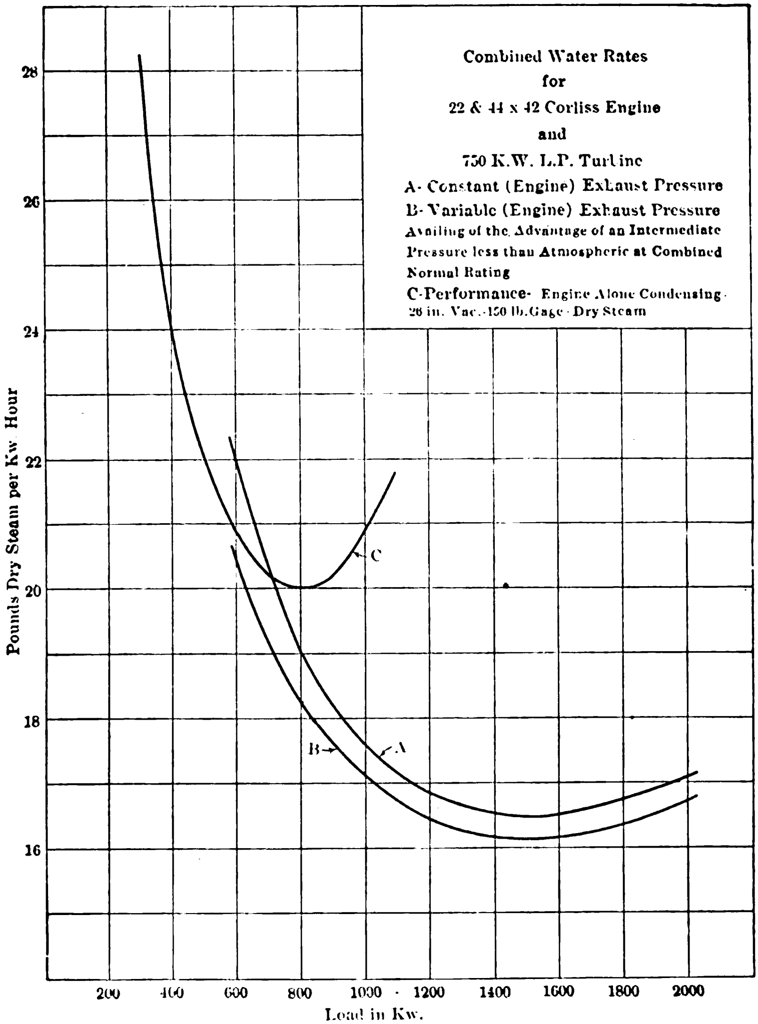


FIG. 1

will give the same Rankine cycle efficiency as a low-pressure urbine at the same vacuum and using dry saturated steam.

The gain in economy of 13 per cent, as stated by Mr. Stott, is what would be expected when we consider that this unit is

operating on dry and saturated steam. I must, therefore, differ with Mr. Rotter, as I know of no complete expansion economies on record that do not agree to a large extent with what Mr. Stott has brought out. A Rankine cycle efficiency of 70½ per cent on a complete expansion machine, but no turbine performance reaching this degree of efficiency has to my knowledge been recorded in this country. Some have gone as high as 67.8 per cent, but as far as I am able to learn, any record of a complete expansion machine that has exceeded 70 per cent is within closed doors.

I am very much interested in observing the results obtained with constant and variable exhaust pressure. When this question first came up in low-pressure turbine work, variable exhaust pressure was looked upon with disfavor by some designers and engineers, while others advocated this method because of the better results obtained with it. It is now quite evident that in the neighborhood of 5 per cent additional economy is obtained by running with variable exhaust pressure. As Mr. Stott has stated, it is obvious that unless the piping and apparatus between the engine and turbine are in very good condition, good vacuum will not obtain. I find, however, that there are a number of low-pressure turbine installations where the low-pressure turbine is coupled with two or more compound Corliss engines with moderately long connections, and they secure a vacuum in the neighborhood of 28½ or 29 in. The overall economy, even in the small 1000-kw. unit, indicates the same relative gain as shown by Mr. Stott's results. Fig. 6 and Fig. 7 in Mr. Stott's paper, show the desirability of variable pressure operation on account of looping of the cards.

Mr. Stott mentioned in the first part of his paper that the maintenance account of a complete gas-engine plant would be from four to ten times that of a turbine station. To the best of our ability in collecting information and judging working conditions, we do not find it comes up to this factor, and the same thing is true in England according to a paper presented before the Institution of Electrical Engineers on November 17, 1908. This paper was very thoroughly discussed at London, Dublin and Manchester. both favorable and adverse comment being made, but the prevailing opinion seemed to be that the maintenance cost of the complete gas plant would not much exceed that of the steam turbine plant; in fact, the author of this paper claimed it to be the same. When the producer and boiler are considered, there is reason for this statement.

Regarding the statement that the results obtained closely approach gas-engine efficiencies, gas-engine coal consumption is usually given for 12,000 to 13,000-B.t.u. coal, but considering 14,500-B.t.u. coal in both steam and gas plants, a material difference of 20 to 25 per cent will easily be obtained in favor of the gas equipment over the most efficient steam machinery.

The value of the low-pressure turbine is rapidly bringing about

its extensive use in connection with the gas engine, availing of the waste heat of the jacket and exhaust.

Charles P. Steinmetz: The paper deals with a combination of the low-pressure steam turbine with the induction generator, which, while possibly not familiar to some, is assuming a very high industrial importance.

The electrical part of the unit, the induction generator, is not a new type of machine. Its existence was known and its characteristics and behavior investigated and discussed many years ago; but only now has the industry developed in such a manner as to give conditions in which the induction generator is preferable to the synchronous generator.

There are two kinds of alternating-current generators: the synchronous generator, which is the ordinary alternating-current machine with which we are familiar, and the induction generator. Constructively, the stator or stationary structure of both types of alternator is practically the same in construction. It comprises a polyphase winding, in which the electromotive force is induced by the rotating magnetic field, arranged in a laminated structure. The difference between the synchronous generator and the induction generator is in the rotor. In the synchronous generator this is a revolving magnetic field excited by direct current; while in the induction generator it contains a short-circuited winding the same as the armature winding of the familiar induction motor. From this variation results the difference in the production of the magnetic field which by its rotation induces electromotive force in the stationary generator winding. The magnetic field of the synchronous generator is produced by the action of the direct current in the field poles; that of the induction generator is produced by the reaction of the alternating currents issuing from the induction generator. As a consequence the synchronous generator must run in step with the frequency of the alternating system; that is, the rotor must move exactly one pole for every reversal of voltage in the external system. Conversely, the induction generator cannot run in step with the frequency but must always run faster, exceeding synchronism by an amount depending upon the load, so as to cause the induction in the short-circuited windings which produces the currents therein. That means that synchronizing is not required in the induction generator. Furthermore, since the induction generator does not depend upon running in step with any other machine, the possibilities of see-sawing, the so-called hunting which may occur in the synchronous machine, cannot exist with the induction generator.

The difference in the production of the magnetic field of the two types of alternating-current generator is the cause of the very characteristic variations in their performance. The magnetic field of the synchronous machine and, therefore, the electromotive force induced in its armature, depends on the direct current supplied to its field winding, but is essentially

independent of the load of the machine. It is dependent only in so far as the current output and the power factor modify the field, varying it in the manner expressed by the term "regulation of the machine". The induction-motor field is produced by the reaction of the currents issuing from the machine. The induction generator, therefore, has no regulation and no magnetic field, independent of the voltage at the terminals and the load, but the magnetic field of the induction machine is produced by the reaction of the currents at a value corresponding to the voltage produced at the induction-generator terminals by the synchronous machines connected to the same system. The induction generator depends in its magnetic field and voltage on the excitation of the synchronous machines in the same system; that is, it can generate only when connected to a system to which synchronous machines are also connected, whether synchronous generators, motors, converters or equivalent apparatus. It has no voltage of its own and cannot operate on a system on which no synchronous machine is connected.

The regulation of such a combined system of synchronous and induction machines, therefore, is the regulation of the synchronous machines operating on the system. Any change of load varies the voltage as it would be varied if this change of load occurred on the synchronous machines in the system. The induction generator is merely a machine feeding electric power into the system but not participating in the voltage regulation or voltage control and having no direct effect on the voltage. While the synchronous machine at open circuit has a terminal voltage, the induction generator ceases to generate and has no voltage at its terminals at open circuit if it is disconnected from the alternating system. In a synchronous generator, even when short-circuited, the electromotive force continues to be induced in the armature windings because the magnetic field is still there as produced by the direct current. The synchronous generator therefore has a short-circuit current which may be many times full-load current, since the total induced electromotive force must be consumed inside of the synchronous generator armature. An induction generator, when short-circuited, has no voltage at the terminals, and therefore receives no current, has no magnetic field, and ceases to generate. In the induction generator when short-circuited, the current dies down from its previous normal value to zero at a rate depending on the resistance and inductance of the internal circuit in just the same manner as the current in a reactive coil, for instance, would die down when the coil is short-circuited and the impressed voltage withdrawn from it. The short-circuit current of the combined system of synchronous and induction generators is therefore only the short-circuit current of the synchronous generators.

There results therefrom also the characteristic difference that the synchronous generator can generate current of any character, energy, reactive or wattless lagging, or leading,

depending on the nature of the system to which it is connected, or the power factor of the supply system; while the induction generator can generate only energy current, and in addition continuously consumes or receives a certain amount of reactive or wattless lagging current required for its excitation. This latter it receives from the synchronous generators or the synchronous motors and converters in the system. The induction generator, therefore, cannot supply alone a general alternating-current system, for instance, a system of light and power distribution, which requires energy current, as well as reactive, or wattless lagging current; and where a combination of synchronous and induction generators is used, all the lagging current of the system must be supplied by the synchronous generators, and in addition the lagging current also consumed by the induction generator for its excitation.

In a system in which there is considerable lagging current, a very large percentage of induction generators is a questionable advantage, since it may throw an excessive overload in current on the synchronous generators, the latter having to supply all the lagging current. On a system requiring no lagging current, or being built to supply lagging current, as rotary converters or synchronous motors, which is the type of system on which Mr. Stott's generators operate and is usual in the large electric power-generating and distributing systems, mainly of 25-cycles, there is no lagging current required because the system can be run at unity power factor or even at leading current, and the synchronous motors and converters can be caused to supply the lagging exciting current of the induction generators. There the induction generator is at its greatest advantage.

The difference may possibly be described by saying the synchronous generator generates electric current while the induction generator generates electric power. That is, the synchronous generator supplies electric current to the system whether this current is a power current or a wattless, powerless current; the induction generator can supply only power current and no wattless current. The induction generator, therefore, is the typical converter from mechanical into electric power. It consumes mechanical power, supplies electric power without depending in its supply on field excitation, speed, synchronism or any other feature. It is consequently the ideal machine to float on an alternating-current system, by receiving whatever mechanical power is available and supplied to it a low-pressure steam turbine from the exhaust steam of reciprocating engines; or in the hydraulic turbine from whatever water power there may be available. It receives the mechanical power and converts it into a proportional amount of electric power, at whatever voltage the system happens to run on, and at any speed, speeding up just above that for which the system is set by its frequency, but with no necessary regulation. Its straight and simple function is the conversion of one kind of energy to the other, separate entirely

from the problem of regulation and adjustment which is thrown over into the synchronous machines in the same system. This is what makes the induction generator a simple and convenient apparatus for cases like that described in the paper and for all others where mechanical power is to be picked up from water powers here and there, and is too small, possibly, to warrant installation of specific regulating mechanism.

There is an interesting and somewhat unexpected result shown by the tests, namely that the efficiency was found higher when operating the turbine with varying nozzle pressure than when operating with constant nozzle pressure. The explanation of this is given by the curves in Fig. 13 and Fig. 14. In the latter the efficiency of the low-pressure turbine is higher for constant nozzle pressure, just as expected, but constant nozzle pressure of the turbine means constant exhaust pressure of the steam engine and with this and the varying load, as shown in Fig. 13, the efficiency of the steam engine falls off, dropping from the maximum point at a rate which is so much greater than the gain in efficiency of the steam turbine that the combined efficiency shows an advantage in favor of varying nozzle pressure. This illustrates the fact that the turbine side is much less sensitive to variations of the operating conditions from its best condition than the steam engine is, and that to get maximum economy in the operating conditions the engine should be favored. But that also throws a side-light on one of the reasons why the Rankine efficiency of the turbine is less than that of the steam engine part, because all the unfavorable conditions of operation must be thrown on the turbine side of the cycle to get maximum average resultant efficiency.

The gain in efficiency due to the addition of the low-pressure turbine is on the lower side of the cycle, because of the possibility of extending the expansion below the exhaust pressure of the low-pressure cylinder of the steam engine, an extension impossible with the reciprocating engine. The combined apparatus gains in the ability of the turbine to do what the reciprocating engine is not able to do. This must be kept in mind when comparing the low-pressure turbine and steam-engine plant with the high-pressure turbine plant.

The reciprocating engine in general cannot gain by superheat as much as the steam turbine gains, and comparison of the combined efficiency of a saturated-steam reciprocating engine and low-pressure turbine with a high-pressure turbine is not quite fair to the latter, because on the high-pressure side, the steam turbine can get an additional gain in efficiency by using superheat which the reciprocating engine cannot to the same extent. In comparing things it is always difficult to get conditions which are equally fair to both types of apparatus because the conditions of proper operations are different in each.

J. W. Lieb, Jr.: The author is somewhat optimistic in his estimate that it would be possible to realize as much as 20 per

cent of the installation cost from the sale of used apparatus. It would probably be necessary to accept a lower figure, but the result, however, would be still more in favor of the installation of the low-pressure turbines.

In the application of the induction generator we have a solution of the problem which combines simplicity of construction and operation with a minimum of installation cost. The induction generator is also of notable assistance in solving the otherwise very difficult problem of handling through the available types of switching gear the enormous energy which might with the usual types of apparatus be difficult to handle in case of a short circuit on the bus bars.

The results of the condenser tests are particularly interesting on account of the high rates of heat transference, considerably in advance of the results hitherto attained.

The paper is a notable contribution to the economics of power plant engineering and the apparatus described should serve to give a new lease of life to otherwise antiquated engine-driven equipments, although it would be difficult to find another case where the application could be made with such manifest advantages.

D. S. Jacobus: I visited the plant of the Interborough Company while Mr. Stott's tests were being made and desire to commend most highly the degree of accuracy observed and the general character of the work.

The economy of all piston steam-engine installations may not be improved as much as 25 per cent by adding a low-pressure turbine. By examining the paper on tests made at the plant of the Pacific Light and Power Company at Redondo, California, presented to this Society by Mr. Weymouth, it will be found that the heat consumption with a steady load with piston steam engines was about 21,800 B.t.u. per kw-hr. The heat consumption was obtained by dividing the heat of combustion of the oil burned at the boilers by the net electrical output in kilowatt-hours at the switchboard. The efficiency in the tests of the combined unit by Mr. Stott is 20.6 per cent based on the heat in the steam consumed, and if we take the efficiency of the boilers at 76 per cent, a figure obtainable with oil, the heat of combustion of the fuel burned at the boilers would be 21,800 B.t.u. The difference between Mr. Stott's figures and those obtained at the Redondo plant is, therefore, about 12 per cent. There is a further allowance for the fact that the steam was superheated about 100 deg. fahr. in the Redondo tests and this would increase the figure and make it come more than 12 per cent. It does not seem possible that the introduction of a low-pressure steam turbine at the Redondo plant could ever reduce the heat consumption 25 per cent, bringing it down to 18,600 B.t.u. per kw-hr.

The results obtained by Mr. Stott are very close to those which can be secured with large gas engines. The economy of 21,800 B.t.u. could be reduced with proper superheat to about 20,000

B.t.u. per kw-hr., which would be all that could be expected of a producer-gas plant if run on a commercial swinging load with high daily peaks and periods of low power. In a 15 days' continuous test made at the Redondo plant where the load varied daily through a wide range from high peaks to periods where but little load was on the station and where there was a lay-over period of 4½ hours per day, the heat consumption averaged about 25,000 B.t.u. per kw-hr. and it is questionable whether a producer-gas-engine installation could do very much better with a load of this character.

Mr. Schauber: In regard to the statement that the result obtained with the engine-turbine-unit had closely approached the best efficiency obtained in gas-engine practice, I desire to call attention to the installation of four 2000-kw. units at the Illinois Steel Company, operating on blast furnace gas. Records kept for six months under working conditions show a consumption of 15,000 B.t.u. per kw-hr. at the switchboard. When this result is compared with the 21,000 B.t.u. per kw-hr. at the 59th Street station, the comparison is more in favor of the gas engine than the statement made in Mr. Stott's paper.

D. S. Jacobus: The 15,000 B.t.u. quoted by Mr. Schauber is based on the heat of combustion of the blast furnace gas used by the engines. If there had been a producer this value would correspond to that computed on the basis of the low heat value of the gas, and where allowance is made for losses through all auxiliaries, this figure would have to be divided by about 0.7 to give the heat units in the original fuel. This would give a much higher heat consumption, say, over 20,000 B.t.u. per kw-hr.

G. R. Parker: The question often arises as to the smallest size of plant in which a low-pressure turbine can profitably be made, and while no accurate data is yet available, I consider it doubtful if very satisfactory results can be obtained in plants of less than 300 or 400 kw. This is due to the fact that the actual cost of producing power in small installations, is not made up so largely of coal as it is in large installations, the labor and the numerous operating expenses constituting a much larger percentage of the cost.

A word of appreciation is due Mr. Emmet for the persistance with which he has worked on the problems of the turbine industry, through many early trials and difficulties, until his latest and possibly his greatest achievement, which Mr. Stott has so ably presented. I feel confident that engineering posterity will give due credit to Mr. Emmet.

O. Junggren: The over-all efficiency shown by Test 51, Table 8, is 72½ per cent of the total available energy between the steam entering the engine and the recorded exhaust pressure of the turbine. Test 42 shows an efficiency of 69.6 per cent, and another, 68.7 per cent under different conditions of load and vacuum. A high-pressure turbine, working under the same conditions of steam pressure and vacuum, would probably not give

as high an efficiency over such an available range of load as that given by the combined unit, but a high-pressure turbine of approximately the same size could reasonably be expected to give 70 to 70½ per cent at the most economical load, although fractional efficiencies would not be as good as for the combined unit. A high-pressure turbine would be considerably cheaper than the combined unit and in the near future high-pressure turbines will be made having as high an efficiency as the combined unit, and still be cheaper than a combination of engine and turbine. The vacuum obtained in these tests are quite remarkable and show what can be done in actual practice.

F. Samuelson said that the field for variable-pressure turbine work, not yet developed in America, has been fully opened up in England and the business is in a very healthful condition. Low-pressure turbines of various types have been employed and all are proving fairly successful. The chief difficulty in the installation of these machines has been to meet the Board of Trade regulations as to constant back pressure on hoisting engines. Accidents are sometimes caused by a drop in back pressure at the engine, due to demands upon the accumulator by the turbine. To prevent this trouble a simple automatic valve has been employed between the engine and the accumulator to shut off the supply from the engine when the accumulator pressure falls to atmospheric. While the regulating valve is closed the turbine is supplied with steam at a reduced pressure. This valve works equally well between the turbine and the accumulator, but the capacity of the latter is much reduced because of the small pressure limit between which it operates. This results in the use of high-pressure steam in the turbine on short stoppage of the engine.

The Author: Refiguring one of the assumed cards (Card C, Table B) for 100 deg. superheat, we get an actual water rate of 12.9 lb. per h.p. instead of 13.6 with saturated steam, since the missing water and leakage is cut to less than 0.1 of the original value in the high-pressure cylinder. As the missing water in the high-pressure cylinder forms about 0.6 of the total missing water, we shall have 0.46 of the original missing water in this case, or $0.156 \times 0.46 = 0.072$, say roughly 0.08. The B.t.u. supplied per hour $= 12.9 \times 9836 \times 1259 = 159{,}800{,}000$. Radiation and conduction, 1 per cent $= 1{,}598{,}000$ B.t.u-hr. High-pressure cylinder work $= 5080 \times 2545 = 12{,}940{,}000$ B.t.u-hr.; this leaves 145,262,000 B.t.u. in the steam at high-pressure exhaust, or $\frac{145{,}262{,}000}{126{,}900} = 1145$ B.t.u. per lb. At 52.2 lb. absolute, this corresponds to a quality of 96.8 per cent or 3.2 per cent moisture; of this about 2 per cent will be thrown down as receiver drain.

The heat thus removed is $0.02 \times 126{,}900 \times 253 = 643{,}000$ B.t.u., leaving 144,619,000 B.t.u. in 124,360 lb. of steam, de-

livered to the low-pressure cylinder. Low-pressure radiation, 0.01×144, $619,000 = 1,446,000$; low-pressure work $= 4756 \times 2545 = 12,100,000$; leaving 131,073,000 B.t.u-hr., or 1065 B.t.u-lb. which at 13.5-lb. absolute exhaust pressure gives a quality of 91.5 per cent, or 113,800 lb. dry steam available for the turbine. This will give 3,700 kw. on the turbine, which added to the 6710 kw. on the engine gives 10,410 kw. at 12.18 lb. per kw-hr. as against 14.2 lb. with saturated steam. In actual practice the 14.2 rate was cut down to 13.25, and it is reasonable to expect the same sort of result under superheat.

The reciprocating engine, when designed for superheat, makes just as good use of it thermodynamically as a steam turbine, but will not stand so much superheat. The point has been raised, that a moisture correction on the turbine is not fair, since without reheating it is not possible to reduce the moisture in the turbine steam to zero. It is fair in this sense, that in order to compare the various water rates on the same basis, it is necessary to reduce all steam conditions to a standard and that standard is naturally dry steam. Moreover, when the moisture gets as low as 1 per cent or 2 per cent the correction is negligible in amount, and the curve of corrected water rate is substantially true. It is quite possible that a separator can be designed that will take out all but 0.2 or 0.3 per cent of moisture; and in this case the correction justifies itself.

Discussion on "Education for Leadership in Electrical Engineering", New York, April 15, 1910 (See Proceedings for April, 1910).

(Subject to final revision for the Transactions.)

Charles S. Howe: I shall not attempt to discuss all of the interesting questions which have been raised by Professor Sheldon, but only one or two points which have struck me most forcibly. Professor Sheldon says that the electrical engineers who have attained an eminence in their profession do not seem to have engineering degrees, at least very few of them have the degree of E.E. Now, we have found in discussing the reports which have come from the various engineering colleges, that very many of the engineering colleges do not give the degree of E.E. One or two of the oldest and most noted of the technical schools in the country do not grant the degree of Engineer at all, and I think that this may account in part, at least, for the fact that so few of these eminent engineers have the degree of E.E.

In discussing the question of leadership and the preparation for leadership, I am led to say a word or two in regard to the education which we are trying to give in the technical schools, which I believe is along the proper lines, whether for the training of the ordinary engineer or for the training of the engineer for leadership. Among other things, we are trying in the first place, to give the students a certain amount of knowledge. I sometimes think that perhaps we lay too much stress upon that. In the past that has been our principal object, but nevertheless, we must give the student a certain amount of knowledge— a great number of facts, and of course, he forgets most of this before he graduates. But far more important than the giving of facts by teaching a few definite things, is the ability in the student to know where to find the things he wants at any time of his career. That is, the ability to search. If he has been properly taught to search he will have received something far more beneficial to him than the few facts which he has been able to digest and carry away with him.

I believe that in our technical schools we have not paid enough attention to this branch of education, that we ought to teach our students to use dictionaries, and encyclopedias, and books of reference, libraries in general, the catalogs of the great manufacturing establishments, the magazines, the special reports of societies, etc., until, when a student is confronted with any problem, he will practically know just where to go to find the proper information upon that subject.

The other thing which we should try to teach him is to think, to reason for himself. That is the hardest task which we have. I believe, however, that it would be possible to lay out a systematic course of instruction in teaching students to think for themselves.

Most men are not leaders, as Professor Sheldon has said, they are men who follow, they follow the men before them, and this

process of thinking is, as a rule, at the present time learned by men themselves, without very much instruction on the subject. If we can only develop methods by which students will understand the laws of learning to think, to think along engineering lines, we shall greatly increase the number of leaders, and I believe the leaders themselves will be still greater leaders.

Professor Sheldon has emphasized the importance of broad knowledge, of facility of expression, etc., and I believe that he has rightly done so. The technical institutions are fast coming to the point where they believe that the instruction in engineering colleges should be broader than it has been in the past. Perhaps it might well be asked why we do not now insist that every student coming to a technical school shall first be a college graduate. The reason, of course, has been that the technical schools have utterly been unable to graduate men enough to fill the places open for them. If all the technical schools required a college degree for admission, we would not be able to graduate more than one-quarter as many students in technical schools as we now do, and there would be a smaller proportion of men ready to take the positions which are open to the technical graduate. That is the reason why, in the past, we have not insisted upon the broader training.

I fully agree with Professor Sheldon also that men should be taught facility of expression. The subject of English composition and rhetoric especially has been greatly neglected in most of our technical schools, until within a very few years. Now we are beginning to devote more time to this subject, because we are finding out that the technical graduates we have been sending out without any ability to write, without any facility of expression, do not succeed as well as the men who can express their thoughts well upon paper and present engineering subjects to Boards of Directors or to organizations like this.

Professor Sheldon also made some suggestions in regard to improvements which might be made in the technical schools. He speaks of new methods of admission. I do not know whether it is possible to find any way of admission by which we shall be able to find a set of men of greater ability, more energy, who will take higher rank in their studies, and who will make better engineers after they get out into the world. I doubt if we can do it by any system of entrance examinations. We can do it, however, by weeding out the students while they are in the college. Of course, the technical school does that now to a considerable extent. I think, possibly, the process at times might be carried further.

Dr. Sheldon has said that new subjects should be introduced. I heartily agree with him. There are many things we ought to teach in the technical schools which we do not teach now. It is also suggested that new methods should be employed, and again I think he is entirely right. Whether it is going to be possible to teach new subjects and use new methods in a four years'

course, I am very much in doubt. I rather think that the technical schools are coming to the conclusion that in the future we must have a five years' course instead of a four years' course. Whether we shall be able to train any more men for leadership, I do not know. Leadership depends upon many qualities. Now, we can only take the product which comes to us, and try to improve it. We cannot make native ability, and some of the qualifications for leadership are the natural qualifications of the man. These we may improve, but we cannot create them.

Another thing which is necessary for leadership is the ability to get along with and to handle men. That is something that it is exceedingly difficult for us to teach in the technical school. It is the man who can work with other men, get along with them, and handle them, who generally achieves the greatest success.

Abraham Flexner: It seems to me that in this country we have been rather apt to concentrate our educational processes on instrumental proficiency, on the making of men who could do particular things efficiently and well—good surgeons, good doctors, good lawyers, in the narrow and professional sense in which those terms are used.

The problem which Mr. Sheldon raises, namely as to how cultural and vocational standpoints can be combined in any one educational discipline, is fundamently a logical before it is an educational problem.

We are dealing here with two apparently exclusive concepts, culture and vocation. We ordinarily apply the term " Culture " to experience in so far as it is expansive, sympathetic, enlarging, releasing; we distinguish from culture " vocation ", as practical, immediate, concentrative, limiting. To the engineer, culture would seem to be art, history, economics; but to the artist, the activities and implications of engineering would have to represent the enlarging, releasing, that is cultural aspects of experience.

The attempt to conceive the cultural and the practical as different in kind would, however, break down of its own weight; for obviously, any one object or interest can be either the one or the other by turns.

If, now, one particular content may, according to point of view, serve in both capacities, being simultaneously culture to one man and vocation to another, it is obvious that the distinction is not really fixed and fundamental. The actual relation, instead of being one of permanent opposition or contradistinction, is, I think, rather to be likened to the relation between a map and any town or state upon it. On a map of the United States the state of Ohio is, the moment one's attention is concentrated upon it, seen as against all the rest of the map. None the less the state is all the time part of the map, from which it is at the moment, and from a particular point of view, abstracted. We can, I think, conceive the logical relation between culture and vocation in some such form.

Within this inclusive mass, certain typical forms are dif-

ferentiated for practical purposes; and any one of them, as seen isolated from, and against the background of, all the others, becomes an occupation, a vocation, emphasis upon which proceeds from practical necessity. Any single aspect, when emphasized, concentrated, separated out, from the mass, becomes then the vocation of the man who is thus engaged. Everything else, representing experience that is beyond him, that he must reach out for and go out of himself to get, is, as we say, culture.

The apparent change in the stuff itself is thus the inevitable consequence of the changed angle from which it is regarded. The vocational view is near and detailed because the eye is fixed, the hand ready to act; the cultural view is vaguer, less responsible, more wayward, because it tends to leave the immediate in order to follow out suggestions and clues. It is indeed a rare individual that takes easily by turns both attitudes towards a single object—as, for example, Metchnikoff can and Goethe could do.

If then, the distinction between culture and vocation is thus shifting, conventional, a matter of convenience, a temporary point of view, it is clear that there is a certain untruthfulness and inadequacy involved whenever the effort is made to isolate vocation from the cultural plexus, to treat it wholly within itself. Provisionally such isolation is, of course, warranted in so far as it serves a purpose. But relations are falsified if the lines are held tight. The inadequacy of a specific and narrow treatment of engineering education, such as Mr. Sheldon has pointed out, is due, I think, to this unnatural separation of the practical ingredients of engineering as a vocation from the social background and interrelations which really constitute the opportunity and content of engineering as a profession.

It is no more possible to realize in its fulness the meaning of engineering or of medicine (when they are taken alone) than it is possible permanently to treat the state of Ohio as an entity. Within any one geographical division there are indeed certain relations to be established and certain facts to be learned. But our knowledge of it is dead unless these threads are followed out beyond state lines into the rest of the map.

If, then, this logical relationship that I have pointed out is sound, it follows that vocational or professional training must have a background, the whole background of our social life, just as the activities and interests of engineering must themselves be part of the background for men whose vocations lie in other parts of the field.

The word cultural cannot then be restricted to any particular set of interests and activities. It is nothing but an historic accident that the untechnical treatment of literary and artistic subjects has come to be specifically known as culture.

The details of an educational scheme which shall seek to put into effect the relationship that has been pointed out can hardly be discussed in the few moments at my disposal. We have

learned well enough how to educate for the vocational life; but not as yet how to achieve the vocational with due deference to the cultural, as the Germans have done; we have yet to solve that problem. The medical schools are just now experimenting with what they call the combined course—the effort, that is, to combine the cultural and the vocational treatment of certain fundamental medical sciences.

The technical training of the engineer, like the technical training of the doctor, is focused on details; it does not lift its eye to follow out into the tangle of life the lines of suggestion that would enrich and diversify and enlarge. It stops at the state line, to recur to the metaphor of the map. And all the time this unnatural isolation defeats itself—for the engineer, like the physician, is one of the builders of the future. The narrowly technical education makes him just instrumentally proficient; only if his training extends out into the cultural tangle, will he get a voice in determining the line that social evolution shall take, only then will he be a creator of the future and not merely a tool of the present.

I wonder if it may not turn out—I speak very hesitatingly here—that the engineering school will have to define its purpose anew, revising its procedure in conformity therewith. Four years do not suffice to produce a highly specialized engineer, with cultural outlook besides; to train a boy in both instrumental and cultural mastery of the art. Perhaps the lines of the technical school may have to be laid down more broadly, on the assumption that a subsequent apprenticeship may shape the young graduate to his definite practical use. Time and interest might thus be gained within or prior to the engineering course for the cultural as well as the technical treatment of the content of its curriculum.

Doubtless such a treatment sounds very leisurely just when we are finding time too short. I believe that economical use of the years available for schooling will make possible interesting and perhaps successful experiments in this direction. At any rate let us not be afraid to experiment. Outside the elementary school we are not as yet, unfortunately, given to educational experimentation. I cannot believe that there is really anything to be feared in conceding to secondary school or college teachers a much freer field of experimentation than they have as yet been allowed. As a matter of fact, the great problem in education as in society, is not how to prevent, but how to secure innovation.

In this new modern world, which the engineer has done so much to reconstitute, we creatures of habit, continue in a futile and feeble way to do the things that have been doing for centuries past. It will take a good deal of philosophic and logical dynamite to blow the thing to pieces and clear the way for a fresh, adequate, and modern construction.

J. W. Lieb, Jr.: We are living in a practical age, a period of intense industrial activity and large accomplishments—ours

is the age of coöperation and efficiency. It is not enough that a given task be accomplished, or a vast public work completed, the world asks also, has it been done efficiently, with a reasonable economy of time and money, and with a proper adaptation of the means to the end.

While this close scrutiny is given to the relation between expenditure of effort and result achieved, between input and output, between cause and effect in the material accomplishments of our times, a scrutiny not less searching and thorough is being directed to our educational methods and their highest product—the college graduate.

One of the important questions occupying the public mind at present, and upon which the searchlight of inquiry is being directed, is this:

Is the college graduate of to-day, the finished product of our universities, our colleges, and our technical schools, occupying a position in professional activities, in the industrial world, and as a citizen, which justifies the expenditure of time, money, and educational effort sacrificed in his preparation?

Is the college graduate successfully fulfilling a distinct mission in our social system not only in furthering industrial developments, not only as a leader in thought and an exponent of culture in its highest sense, but also as an effective force making for righteousness in the community, and is he making his service and sympathies felt in the uplift and progress of humanity?

Is his success in life—measured also by purely commercial standards—such as to demonstrate without question that the time and expense necessary to produce him, is a wise investment?

I think Professor Sheldon has afforded several clues to the consideration of some of these questions. He has referred in his paper to the specialization in the field of electrical engineering. This hardly needs emphasis, as we know that in our institution, the American Institute of Electrical Engineers, we are beginning already to sub-specialize within the domain of electrical engineering, and we find that this subject of itself is becoming already too broad for one man to become expert in all of its ramifications. This has also taken place in the past history of the broader field of engineering, and now the technical schools in mechanical engineering find it most difficult to fairly cover the field with the tremendous expansion which electrical engineering has brought about, and they are face to face with the proposition of subdividing their courses into the several constituent fields.

Dr. Sheldon has referred to the importance of facility of expression, both oral and written. This is a subject which appeals to me very strongly, because as a matter of experience, I have found that it is one direction in which the product of our technical schools is most apt to be deficient. The product of the technical school has had strongly instilled into him the power of analysis,

the method of approach, the weighing up of the pros and cons of a problem, but it is my opinion that he has not been sufficiently well grounded in the power of expressing and of presenting his conclusions. This is a most important element, a most important faculty, which the successful engineer should possess if he wishes to present his findings and have them adopted; the power to clearly and strongly present his views, to be able to defend them with good judgment and force, so as to impress the people who are to place their money upon his judgment. In this particular direction it appears to me that our technical schools might well devote a larger share of attention.

It has seemed the purpose of the discussion to take up the suggestions which Dr. Sheldon has made as to the modifications in the present methods of technical instruction. As one grows older, one feels the lack of the broader culture to which repeated reference has been made, which it has not been possible for the technical schools to give. This is a serious proposition, as we are already face to face with the evident necessity of expanding the course from four to five years. This expansion is of pressing importance, from the standpoint, one might say, of vocational requirements, and where, usually, the time for a wider acquaintance with the humanities is not afforded. This is a serious question which the engineer is facing. It is almost impossible for the engineer to make up for lost time after graduation. The necessity of following the tremendously rapid developments in all of the fields of engineering makes self-culture a matter of extreme difficulty; and therefore, the most that the purely technical school can hope to accomplish is to instill into the minds of the students a love for purely cultural studies, for literature, and art, in all their various manifestations, in the expectation that they may be followed during more mature opportunities that come in after professional life.

We all know that the responsibilities resting upon the engineer are ever increasing. Many subjects, such as old-age pensions, systems of compensation for labor, prison labor, child labor, and subjects of this character, are left in the hands of lawyers or professional politicians. Now, this should not be the case. The professional engineer who has come in contact with these subjects in their various manifestations should take a more active part in developing the public mind and directing the activities of the state and the nation in the direction of meeting these living questions. In order to do this it is necessary for the engineer to have something more than a merely vocational training, it is necessary for him to have a wide basis of culture, wide human sympathies, and a wide knowledge in many fields; and it is to be hoped that our technical schools will rise to the opportunity of conferring upon their students a more thorough recognition of the value, even to the vocational man, of a broad basis of culture and entertainment.

A. E. Kennelly: Some of the statistics presented by Dr. Sheldon, while they seem strange at first sight, may perhaps

be explained without great difficulty, as he has himself suggested. For example, the fact that there are comparatively few electrical engineers with the degree of M.A. is a fault that time will rectify; because there has not been opportunity in the past to obtain many electrical engineers among the men who have received that degree. Again, the fact that we have no notable electrical engineers over seventy-four years of age, ought not to be interpreted on the understanding that the good die young, because the profession is still too juvenile.

In regard to the vexed question as to what subjects are cultural and what subjects are vocational, I would venture the proposition that all subjects are either vocational or cultural merely according to the way in which they are taken and given, and that there is no other criterion. In fact, I would go so far as to say that in a certain sense all subjects are equally worthy and equally grand. There is no subject which, of and in itself is more worthy or more deserving of study than any other subject, if treated in a broad sense. It is only when considered with reference to some particular vocation, or some particular duty that certain studies become of preeminent importance. The selection of specific technical subjects of study is of absolute necessity, in order to economize time; because the training years are limited, and we cannot indefinitely stay in school.

In regard to the requirements or qualifications for leadership, I think we must all agree with Dr. Sheldon in the general propositions that he offers, but I think there is one item that deserves some emphasis; namely that the qualifications which are competent to train men to lead are also qualifications that train men to follow; that men, before leading, must be able to follow, and that the requirements of the man who shall follow are discipline, and faithfulness, and earnestness in whatever he undertakes.

It seems to me that the qualities for training in following, depend largely upon the cultivation of ideals. Ideals cannot be created any more than learning can be created, but ideals can be fostered.

I believe that the elevation of ideals is of the greatest importance, so that anything we do, whether we sweep a floor or put up a station, may be done with the best of our ability, and with whole soul. By that criterion alone is our work to be judged.

William McClellan: I think it would be interesting if Dr. Sheldon, in connection with Table 7, would arrange to weight the various qualities, instead of considering them all of equal value, so that when we come to the general average, we should have some way of discovering whether the judge would claim 1.83 or 1.12 as a direct comparison. In other words, would he consider "training the mind", "comprehensiveness of knowledge", "facility of expression", "discipline of the will", and "aesthetic taste" as all of more or less equal value.

We all look at questions of this sort from different points of

view, and as I think of the men whom I should consider leaders in electrical engineering, I find that their leadership is not on account of their wide knowledge of electrical engineering but is due to their having the same qualities that make certain lawyers, clergymen, or medical men leaders. That is to say, it is these characteristics or attributes of the man, himself, which give him leadership and that these characteristics or attributes are general.

Now, it may be stated quite positively that a large accumulation of detail information does not make a man a success. Success comes from reasoning along original lines,and such reasoning is possible only if the man has a thorough understanding of fundamental underlying principles.

History has shown that a physicist or a chemist with a thorough understanding of the composition or properties of matter has been able to do engineering work of the highest order when called upon, although his training in details of engineering has been very scanty.

The possession of this general fundamental information by a man on leaving college is all the more important when it is remembered that, for the most part, he is hunting for a job and is willing to take it in any branch of engineering, whether in the particular one for which he prepared or not.

I believe that there is sufficient evidence now of a change in our educational courses to show an effort to produce men trained as engineers rather than as certain kinds of engineers. Unity is being introduced gradually; and, perhaps, some day, we shall have a broad profession of engineering, like, at present the professions of law and medicine.

Personally, I should be very glad to see the colleges of the country give up all consideration, in the undergraduate courses, of special engineering degrees; and give to all their students the same course, graduating them with the degree of Bachelor of Science.

In the arrangement of our college courses, we could learn a great deal from a consideration of what is done in medicine and in law where the undergraduates take practically the same studies barring, perhaps, a few electives in the senior year, and specialize when they get out into practical work.

President Stillwell: I want to call attention to two things that have been emphasized particularly. In the first place, I do not agree with Mr. Lieb entirely with regard to what he said about the difficulties of self-culture after graduation. I believe that the man who stops his education upon graduation, and exclusively specializes, makes a great mistake. There are any amount of opportunities for a man to continue his education in a manner that is broadening and effective. The other suggestion is this; that education in almost any line that teaches logic and a sense of proportion is engineering education. In constructive engineering the most valuable faculty, in my judgment, is that which may be designated as the sense of proportion, what the painters would call perspective.

In one large engineering undertaking some years ago I had occasion to have the number of contracts determined which entered into the equipment; which had nothing to do with civil engineering, nothing to do with the digging of holes in the ground, but simply with equipment, mechanical and electrical. These contracts were not divided, they represented links in a chain. There were one hundred and seventy of them. Now, I think it is not often realized that there are so many factors entering into a large modern engineering construction in the electrical and mechanical field. No mathematician can possibly produce an equation representing the values of the factors entering into that aggregated plant. The mental characteristic, which is comparatively rare, and which after all is the most valuable, is something which may come partly from education, but I believe it is largely innate, that is, proportion and judgment, to determine relative values, and to aggregate the factors which enter into one of these complex matters in a manner that will produce an operative, well balanced and economical result.

Wm. J. Berry: The discussion of this paper has been very interesting, and all the speakers seem to be in substantial agreement with the writer. It is surely most significant that men who have attained eminence in the practice of their profession have joined with educators in pleading for a broader training for the engineer. It seems to me, however, that we are in grave danger of losing sight of an important factor in the problem of engineering education—the student himself. There is a certain limit beyond which not even the best student can work efficiently, and in planning our curricula, care must be taken not to exceed the average limit of the students who remain after all the elimination tests, to which reference has been made, have been applied. Some of the " haste which kills perfection," of which Professor Sheldon speaks, has, undoubtedly found its way into our technical schools through a desire to do more than can be accomplished with thoroughness in the allotted time.

The college of the humanities, aiming to give cultural training, applies to the subjects studied the extensive and appreciative method; the technical school, the purpose of which is vocational instruction, employs the intensive and critical method, yet the latter institution usually requires a greater number of courses than does the former. Harvard College demands for the bachelor's degree a minimum of seventeen and one-half courses (or the equivalent in half course.) of which not more than six may be taken in any one year. recently there came to my notice the case of a student in an engineering school of established reputation, one of the best two men in his class, who, at the end of the first semester of his senior year had to his credit the equivalent of sixty-one half courses, representing a total about double that of a college senior, and an annual average of seventeen half courses as compared with the latter's maximum of twelve. The college man spends from fifteen to twenty hours

a week in attendance on lectures, the technical student devotes from thirty to forty to required work in the lecture hall and in the laboratory.

We are all agreed that the ideal training for the engineering leader must consist partly of vocational and partly of cultural subjects in the sense in which those terms were defined by Dr. Flexner, but even with the five years course suggested by Professor Sheldon, not many new subjects can be added to the existing curricula, unless it be possible at the same time, to eliminate some of those already present, or better methods of instruction can be found than any now employed.

A. S. Langsdorf: It seems to be the general opinion of contributors to discussions on engineering education that the average product of the traditional four-year course is, if not actually mediocre, at least so little beyond that stage as to be damned with faint praise. Most criticisms of the usual curriculum are so vague in their constructive tendencies as to be valueless, while many offer remedies impracticable because of the limited time available. But to whatever extent the strictures are justified by the facts, it cannot be questioned that Dr. Sheldon has gone to the root of things by pointing out the necessity of adopting a new system of selecting entering students; for that, to my mind, is the crux of the whole problem. It may well be doubted whether refinements of the course of study are of any value to a student who lacks some generations of cerebral development, no matter whether that lack be due to heredity or to early environment.

Any one who has had to do with the administration of technical schools knows very well that the hardest work falls upon those whose duty it is to eradicate from the freshmen mind the "kindergarten idea" of education. Our preparatory schools are so strenuously engaged in maintaining the pupils' interest that there has been a distinct loss in the disciplinary features that make for real efficiency; the interest of the student is an important element, but it is not the paramount issue.

The institution which aims to develop leaders as its principal output, and not as a by-product, must deliberately put aside the temptation to brag about the size of its student body, and must recognize the fact that there is such a thing as an aristocracy of intellect. While any man is the better for a schooling, it is given to few to be educated. It has been said that the American standard in higher education is a rather high average and a corresponding low maximum; what is wanted is an educational "load curve" with more "peaks", or at any rate, higher ones.

Signs are not wanting that technical schools are alive to the demands being made upon them; witness the developments of recent years in the way of lifting engineering education to a really professional basis by the introduction of more or less complete graduate courses. It is a practical certainty that engineering education is going through the same evolutionary process

that has characterized the development of medical education, and for identical reasons.

Samuel Sheldon: In reference to the discussion of Mr. Howe, with regard to my recommendation that a new system of selection of entering students should be adopted, I think it is well recognized that nearly one-third of entering freshmen should never have come to the technical school. What they lack is not that which the school or any one else can give them, but is natural ability. Examinations, conducted along standard methods and lines, cannot determine much else than the candidates' acquired abilities. There should be, it seems to me, for proper justice to those who are expecting to become educated, an examination that will determine whether or not the proper natural traits are present.

Discussion on "Some Developments in Modern Lighting Systems", New York, May 17, 1910, (See Proceedings for June, 1910.)

(Subject to final revision for the Transactions.)

Paul M. Lincoln: I would first question the suggestion made by Mr. Stone of installing a separate set of non-condensing engines driving electrical generators all for the purpose of operating the auxiliaries to the main plant. Many, possibly most engineers, will not agree to this as an advisable course to pursue. In my opinion steam plant auxiliaries should be divided into two classes—first, those whose continuous working is absolutely essential to the operation of the plant, such as exciters, condensing water circulating pumps, power house lighting, boiler feed pumps and dry air pumps. This list includes practically everything in the ordinary plant whose continuous working is absolutely essential to the operation of the plant. The second class of auxiliaries are those whose continuous working is not essential to the operation of the plant such as coal and ash handling machinery, cranes, house service pumps, etc. In my opinion the first class should be so installed that it will require nothing but steam pressure on the boilers to operate them, that is, there should be no electrical generating link whose operation is essential to the operation of these first class auxiliaries. The second class of operations is often widely distributed about the plant and the temporary interruption of their operation will not interfere with the successful operation of the plant and they may be successfully operated by power from the main bars. It should be borne in mind that economy is not the first thing to look after in the operation of auxiliaries. Considerations of boiler upkeep demand that feed water shall enter the boilers at a relatively high temperature. It requires, roughly, that something like 10 per cent of the total heat should be put into the water before that water is allowed to enter the boilers. This is purely a consideration of upkeep in boilers. Therefore, up to the point where the auxiliaries take no more steam than enough to do this heating their economy is not an important point. Simplicity and reliability is a great consideration in this class of auxiliaries and Mr. Stone's suggestion does not make for such simplicity.

The second point in which my opinion differs from that of Mr. Stone is where he says: "The simplest form of low pressure turbines, of course, is that one containing the condenser in the base of the machine, etc." If this statement was restricted to the question of compactness instead of simplicity, I might have been more ready to agree, but as it stands I must dissent. A steam turbine performs one function and its condenser another. To combine both of these functions within a single piece of apparatus makes for complication, not simplicity. So far as my information extends, also, the only type of condenser that is suitable for incorporating in the base any steam turbine is the

surface type, thus making such a combination unit unsuitable for the many cases where a jet or barometric condenser is desired.

There is an apparent inconsistency in regard to devices for the purpose of limiting the current rush in large alternating-current generators. In one paragraph it is stated that reactances designed for this purpose " must be of the coreless type " and the next succeeding paragraph states that in a particular instance, which is cited, " reactances are incorporated in the design of the step-up transformers or compensators ". That these step-up transformers or compensators are not of the coreless type is indicated by the fact that they are designed for low saturation.

To speak briefly of this matter of limiting current rush in alternating-current generators, any designer who has had to do with large alternating-current generators has come face to face with this problem and has realized the necessity either of bracing the generator windings so as to withstand the tremendous mechanical shocks due to short circuit or of reducing the shocks by introducing external reactance. The severity of short circuit shocks increases both with increase of capacity and with increase of speed, (or with decrease of number of poles). The modern tendency is towards larger capacities and higher speeds, consequently the problem of how to take care of mechanical shocks has come prominently before electrical engineers during the last few years. So far as I am aware, the first introduction of reactance coils to reduce these mechanical shocks was in connection with the generators of the New York, New Haven and Hartford R.R. These generators in the early days of their operation were often subject to severe short circuits, sometimes as many as twenty or thirty per day. Although the bracings of the windings of these generators were such as to have withstood a few short circuits without damage, the continual hammering due to the large number of short circuits was harmful; consequently reactances were designed to limit this current, and installed considerably over a year ago. These reactances are not of the coreless type, but have laminated iron circuits with an air gap of proper length as a part of the magnetic circuit. The performance of these reactances is such as to indicate that properly designed iron magnetic circuits may be used in such reactances with entire success. There is admittedly some sacrifice in the reactive effect of an iron core reactance coil owing to the eddy currents in the iron at the time of the establishment of a short circuit. With properly designed and properly laminated magnetic circuits these eddy currents in the iron become reduced to such a point that the advantages of the iron core in such a reactance considerably outweigh the disadvantages of not using it.

In reference to the split-pole rotary converter, my only comment at this time is to repeat my general conclusions which I quote from the transactions of two years ago, as follows:

"In conclusion, it is my opinion, for reasons set forth above that the split pole rotary has disadvantages that far outweigh its advantages when compared to the alternate, a normally developed converter with a synchronous booster of the same number of poles, mounted on the same shaft."

I have not yet had occasion to change the opinion thus expressed two years ago.

Mr. Stone lays considerable stress upon rapidity of action of feeder regulators. Rapidity of action has disadvantages as well as advantages. It must be remembered that feeder regulators, as designed up to date, have incorporated in their design no device to prevent hunting or overrunning such as is inherent in the Tirrill regulator. Increased speed makes for increased probability of the regulator overrunning and not stopping at the proper point after it has started the voltage either up or down. There is a definite limit to which the speed of such a regulator can be increased without getting into trouble of this kind. This speed limit is easily within the range of either the induction type or the switch type. There are two methods in common use of operating automatic regulators; one is to start and stop a motor so geared as to move the regulator and the other is to throw in clutches upon a motor that is constantly running. Either type of operating mechanism may be used with either type of regulator. The question of the inertia of moving parts of the regulator itself is apt to be greatly over-estimated in the case of the induction type of regulator. An investigation will show that the driving motor on the average regulator has an amount of stored energy that is from 100 to 1000 times that of the regulator itself.

I do not agree with Mr. Stone in his conclusion that the switch type of regulator is the best on those circuits where the load is changing more or less rapidly. In my opinion the switch type of regulator is a distinct step backward. For years engineers have recognized the great disadvantages of the switch or step-by-step type of regulator. The moving contacts inherent in the switch type have been entirely avoided in the induction type and it is this fact that gives the induction type its tremendous advantage. The question of speed is merely a matter of driving mechanism and each type comes amply within the limit of the highest practicable speed.

Farley Osgood: It occurs to me that Mr. Stone's suggestion of an auxiliary steam plant to drive the auxiliary apparatus in connection with the power station may be very useful, but I would like to have him tell us if he can the relative of economy of the auxiliary steam plant to drive the auxiliary apparatus connected directly to the boiler system, as compared with a similar steam system being connected to the third or fourth stages of a turbine. Unfortunately, large turbines will go out of business as well as small turbines, and it occurs to me, as an operating man, that there might be times, when if we were operating such an auxiliary system from the prime mover

as it were, if anything should happen to the prime mover, our auxiliary outfit would be disabled as well, and the relations of economy between an auxiliary system directly driven from the boilers may be more beneficial to the operating company, than an auxiliary system driven from some stage of the turbine units.

Concerning the grounded neutral, of course we all know there is a general diversity of opinion upon the advisability of grounded neutral, and from my personal experience, it seems to depend very largely on the ratio of distinctly overhead circuits to the total number of circuits; in other words, if a system is made up largely of underground cable, the grounded neutral may be very beneficial, but in a system which is very largely overhead, the grounded neutral would seem not to apply to such a system, but is rather a detriment than otherwise.

In connection with exciting equipment, I would ask Mr. Stone if he would figure on duplicate equipment of exciting units, or triplicate equipment. Often the exciting equipment will entirely fail, and if it is necessary to install triplicate exciting equipment, especially if we are to have an auxiliary plant, it will make a difference in the estimates of expenses for which the operating officers are held directly responsible.

Mr. Stone: In regard to reactances, as I tried to explain, if we could build the compensator without iron and get the reactance in, we would prefer to do it. So far, we have to build the compensators with iron, and make it as good as possible by designing it as low as possible on the saturation curve. I disagree as to the efficacy of reactance with iron. It certainly cannot respond as quickly to the short circuit conditions as a coreless type would. It is probable that in the case cited by Mr. Lincoln, that it did all that was necessary to do, but one must bear in mind that that system is a small system, and in some of the large systems of 200,000 to 250,000 h.p., to which I tried to confine the discussion, I am sure we would have to modify it a little and use the coreless type.

Another thing, the reactance is not installed to protect the generator windings—that is an incident. The principal thing of interest is the protection of other apparatus in the system. I have seen a short circuit in one of these large systems due to the short circuiting of the current transformer, which was carrying about four times normal load, before it was found out, and the way it was found out it was when it broke down, and the short circuit was violent enough to blow out a 16-in. brick wall in a room 30 ft. long, 20 ft. wide, and 12 ft. high, and it created general havoc in the station, blowing out every compartment door in the entire station, 80 ft. long. The reactance is used for that as well as for the protection of the generator.

Another question brought out was that of raising of the temperature of feed water as affecting the boiler upkeep. That is one reason why feed water is heated. The other reason is the greater economy that can be realized from reheating the feed

water, because the boilers steam better. It is a question of pure economy. In many cases live steam is taken to heat feed water, and great economy is realized, not only in the cost of maintaining the boilers but in the actual coal consumption.

As to the question of high speed regulators, I think that is a question open to discussion. Mr. Lincoln points out that both switch type and induction type regulators can be operated in the same manner. I have personally followed many regulator installations where clutches on both switch type and induction type, have been used, and individual motor drive on both devices, and the starting and stopping motor on both types, but I have never seen any regulator that approached the time of operating, that the switch regulator would, and I have yet to see a switch regulator hunt.

Mr. Osgood brought up the question of using steam direct from the turbine. In all plants we must have auxiliaries. The question is how to drive them. If we drived them by means of steam engines, or turbines, and use no electrical means, perhaps that is the simpler way, but, on the other hand, my opinion is that the straight induction motor, is a somewhat simpler form than a small reciprocating steam engine or steam turbine, and in most cases where these have been installed, I think the books of the companies will show that one of the principal items of upkeep of the stations is the up-keep of the small engine driven auxiliary, and in other cases, where motors are used, no such high costs are realized. My suggestion of the auxiliary plant in the main steam station, was for large systems. I would not advocate it in small systems, but only in the larger systems, where the expenses warrant it. It may be a complication to have an electrical system, but, on the other hand, I think it is open to question, and I think a great many engineers will uphold me, that the electrical system is simpler, and the question then is how to drive the electrical system. If we drive it from the main system, we are open to the possibilities of trouble originating outside in the form of short circuits on the line, feeders, cables, etc. If we drive it from an auxiliary plant in the station, it is not open to the difficulties from the outside but only subject to its own particular trouble, but being in the main station, under the expert care of the operators, it should be the most reliable part of the system.

Mr. Osgood asked if I would advocate two or three exciters. Naturally, that would depend on how the system is operated. In a system where the sections are divided, I think it would be preferable to operate two exciters on each section, either one of which is sufficient to carry the load. I should recommend that these exciters be protected on the alternating current side with overload circuit-breakers, and on the direct current side with reverse current relays. This practice is coming into use in a number of places.

I think Mr. Osgood's point in regard to the ratio of the over-

head to the underground systems is a good one, and one which I overlooked in the paper. In this paper, I confined my attention more generally to the large systems, where all the work is underground, but there are also many other systems where a large proportion is overhead, and I think his question is pertinent in that connection. I would not recommend the grounded neutral except after careful study in such systems as Mr. Osgood cites.

DISCUSSION ON "METAL FILAMENT LAMPS", NEW YORK, MAY 17, 1910. (SEE PROCEEDINGS FOR JUNE, 1910.)

(Subject to final revision for the Transactions.)

Clayton H. Sharp: I would refer for a moment to the importance of the tungsten lamp in street lighting. At the present time it would seem that our older illuminants for street lighting are on the decline. The arc lamp, as we have it, is being superseded by the more powerful arc lamps which have more recently been produced. The series incandescent lamp with the carbon filament, a lamp which never was very satisfactory for its purpose, has been most certainly pushed aside by the tungsten lamp. Not only this, but the advent of the tungsten lamp with its high efficiency and long life and favorable color has enabled the electrical engineer to go into fields of street lighting which previously have been practically closed to him, and which

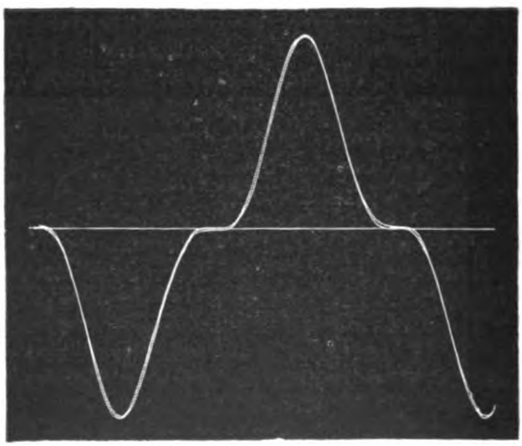


FIG. 1

have been the exclusive domain of other less convenient and less satisfactory illuminants. I wish to point out further that there remains now the next stage, which is to provide means for utilizing more efficiently and satisfactorily the flux of light which the tungsten lamp produces in order to extend its usefulness in the range of street lighting still further. Such plans have been under consideration, and I recently had the pleasure of presenting to the Illuminating Engineering Society the details of a form of reflector by which the light which under ordinary circumstances is wasted by being thrown to the heavens, or thrown to the sides of the streets where it is not wanted, is directed into the dark portions of the street, midway between lamps, where such additional illumination is most desired. Along these lines I think the next step in progress is to be made.

I wish to refer also to another feature of the tungsten lamp

which is intimately connected with the over-shooting of current at the moment the circuit is closed, due to the large positive temperature coefficient. Anothing thing results from this, which is perhaps of academic interest only, and that is that the change in resistance of the filament during a cycle of alternating current necessarily lags somewhat behind the change in electromotive force, on account of the thermal capacity of the filament. Since the resistance of the filament lags behind the e.m.f., the current in it must lead the e.m.f. by a certain small amount and the lamp is not strictly non-inductive, but behaves as if it possessed a certain electrostatic capacity. In an attempt to demonstrate this effect, an e.m.f. having an extremely peaked wave was built up using the harmonic synthesis set of the Electrical Testing Laboratories. This wave form was selected

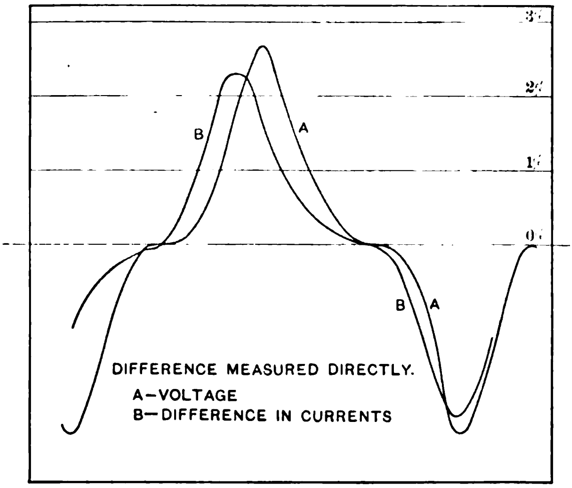


FIG. 2

so that the effect might be exaggerated as much as possible. Wavemeter curves were taken of the e.m.f. and of the current in a 25-watt 110-volt tungsten lamp with a frequency of 25 cycles per second. This frequency was chosen as being as likely as any to give a maximum effect. Too high a frequency would not permit the filament to cool enough during the zero portion of the wave, whereas, if the frequency were too low, the rate of change of e.m.f. on the lamp would be too slow to enable the effect to be seen. The curves of current and electromotive force are shown in Fig. 1, and the phase angle between them, though small, can be clearly appreciated. In order to make the difference more effective, the tungsten lamp and the carbon lamp were connected as the two arms of a Wheatstone bridge, while the wavemeter was used to determine the wave form of the electromotive force across the diagonal of the bridge. This gave a wave which is shown in Fig. 2.

The resistance variation of the tungsten lamp during the cycle was measured, and the minimum value of resistance was found to be about 10 per cent less than the maximum value. The power factor as roughly calculated was found to be 0.99975.

John B. Taylor: Dr. Sharp has just been enlarging on what he calls a feature of merely technical interest, and that is, a slight improvement in power factor due to the substitution of tungsten lamps for carbon lamps.

I think there is a much more practical point directly connected with this matter of positive temperature resistance coefficient, in the fact that the lamp cold takes a much larger current than when in normal service. Resistance curve, Fig. 3, of Mr. Howells paper, shows a cold resistance of 50 ohms, and a hot resistance of 650 ohms, or a little more than thirteen times greater. An oscillograph actually shows a peak value of current about eight times the normal. This difference is due partly to the fact that the lamp has risen slightly in temperature before maximum deflection of the oscillograph, but mainly to reactance and resistance in the circuit. In practice the initial current may be five to eight times the normal value. Usually this large rush of current is not important, but imagine the case of a general shut down on a large interconnected Edison system. Even with carbon lamps there is difficulty in getting under way again, for the reason that all the different substations cannot be connected at the same moment, and the ones that come in first get more load than they can carry. This difficulty with carbon lamps, will be more serious with tungsten lamps. In an isolated plant, if the main breaker opens and it is attempted to throw in the load again, at this one switch, instead of breaking up the system at feeder switches, the generator will be momentarily overloaded five to eight times, depending on line drop and other matters. This may not be a serious matter with some machines, but it cannot be dismissed without investigation. Fuses are not liable to blow on account of the short interval of time during which the current has the large value, but circuit breakers with less time lag may be tripped, and the excess load may cause mechanical troubles or flashing at the commutator. These points deserve consideration.

Another point I want to bring out is more academic. Mr. Howell says: " This excessive current is of sufficient duration to cause an instantaneous rise in candle-power, which is higher than the normal candle-power; this effect has been called " overshooting." I believe I am responsible for the term " overshooting " having used it two years ago when describing the effect in one of the technical periodicals* with photographic records demonstrating that it is a real " effect " and not a mental impression. The point I want to make is that the positive temperature resistance coefficient and excess current will not explain " overshooting " unless it can be shown that there is a time

***Electrical World*, April 25, 1908 and May 16, 1908.*

lag between temperature of a body and its electrical resistance. The temperature is going up very rapidly, perhaps 100,000 degrees cent. per second, but that is no reason why, merely because it is rising so fast, it should continue rising beyond the ultimate temperature determined when balance is reached between energy radiated and conducted away and energy supplied. The only thing I suggested, when I showed the photographic evidence of overshooting was that it might be some secondary action, possibly connected with gases absorbed by the filament, which before begin driven out might modify the resistance for a very brief time. I think the present tungsten lamps do not show the " overshooting " to the extent that the early ones did.

Farley Osgood: I think I may be pardoned if I bring up a point which is purely financial or commercial. The discussion so far has been confined entirely to the physical side of the lamp, and the various problems, theoretical and practical, pertaining to its improvement in efficiency, but there is another point which to my mind is equally important, especially to the users of the lamp, who are quite as much to be considered as the makers of the lamp. Of course, the manufacturers advocate the use of the highest efficiency lamps of the metalized filament type, but my experience is that it is still an open question as to whether or not the metalized filament lamp is an economical proposition for an operating company using a million lamps or more per year. The product of metalized filament lamps of the not most perfect type, namely, all lamps except tungsten, is still so uncertain that the economical average life of such lamps does not from a saving standpoint warrant their introduction on a free renewal basis by operating companies. Most of the operating companies in the country have free renewals of the older type of carbon lamps among all consumers of electric current, and although the total average of metal filament lamps show such a life as to be equal to the carbon lamp, our investigation seems to show that such a result is brought about by the unusually long life of some of the lamps put under test. A few lamps will give extraordinarily long life, and a large proportion of lamps will give not so long a life in the life test, so that although the advocates of the use of this lamp, namely, the manufacturers, are able to show that these conditions are equal between carbon lamps and metalized filament lamps, the operating men are unable to realize it from a financial standpoint. If a greater portion of the lamps show shorter life, and the equal average life is occasioned by the abnormal continuance in service of a few lamps, the expense, from an operating company's standpoint, will increase greatly rather than remain the same. I think it is an open question whether the metalized filament multiple lamp should be used on a free renewal basis, unless the operating companies decide that it is desirable to spend a considerable additional sum for incandescent lamps for the sake of the various benefits which accrue to the consumer by the use of the metalized filament lamp.

In the street lighting service, the condition is almost entirely changed. The tungsten filament lamp can be safely said to average a life of 1500 hours, so that its use is equal to, or better than, the carbon series filament lamp; the renewals are less frequent per year, and the financial results, particularly on account of the lower current consumption, are beneficial to the operating company using tungsten lamps for series street lighting purposes. But I do not think these facts should be lost sight of in the consideration of a more modern or metalized filament type of lamp, and I do not think it amiss to bring out at this time some of the uncomfortable features of the metalized filament lamp as many of the consulting engineers of this Institute have before them for decision such problems for the companies which they represent.

William L. Nodell: I wish to add to the information which Mr. Howell gives concerning tungsten automobile headlight lamps. These are now made in candle-powers ranging from 10 to 25 and operate satisfactorily at the excellent efficiency of 0.8 to 1.0 watts per c.p. They are recommended to be used at 6 volts (3 cells of storage battery) though lamps suitable for other voltages are furnished.

Mr. Howell's paper may give the impression that the normal commercial rating of tungsten lamps is still 1.25 watts per c.p. This is no longer the case, the efficiency being better in lamps of 60 watts and higher, as may be seen from the table given herewith, showing the watts per candle-power and life obtained since the 3 voltage method of rating tungsten lamps has been established:

TUNGSTEN REGULAR MULTIPLE LAMPS FOR 100–125 VOLTS

Designation total watts	At top voltage			At middle voltage			At bottom voltage			
	Watts per c.p.	Nominal mean horizontal candle-power	Hours useful and total life	Watts per c.p.	Nominal mean horizontal candle-power	Hours useful and total life	Watts per c.p.	Nominal mean horizontal candle-power	Hours useful and total life	Horizontal c.p. multiplied by this reduction factor = spherical candle-power
25-watt	1.33	18.8	1000	1.39	17.4	1300	1.45	16.1	1700	0.78
40-watt small bulb	1.25	32.0	1000	1.30	29.9	1300	1.35	28.0	1700	0.77
40-watt large bulb	1.25	32.0	1000	1.30	29.9	1300	1.35	28.0	1700	0.77
60-watt	1.20	50.0	1000	1.25	46.5	1300	1.30	43.5	1700	0.78
100-watt	1.15	87.0	800	1.20	80.8	1000	1.25	75.2	1300	0.78
150-watt	1.15	130.3	800	1.20	121.1	1000	1.25	112.8	1300	0.78
250-watt	1.10	227.3	800	1.15	210.0	1000	1.20	195.0	1300	0.77

Figures furnished by the N. E. L. A.

The philosophy of the three voltage plan is that formerly applied only to gem lamps. Since May 1, 1910 this method of rating is applied to all incandescent lamps, tungsten, tantalum, gem and carbon. A lamp is no longer identified by candle-power and watts-per-candle power but is designated by watts; the efficiency at which it is to burn being determined by the selection of top, middle or bottom voltage. Exceptions to this general rule are miniature lamps and the 4 watt per c.p., series-burning railway lamp, which will be known, as heretofore, by their candle-power.

Referring again to Mr. Howell's paper regarding spring supports to prevent sagging of tungsten filaments; though molybdenum supports are being used for this purpose by some manufacturers, the alleged benefit to be derived is not sustained by the general experience of the majority of manufacturers who have, after exhaustive tests with every known method of support, finally adopted the copper hook at the tip end of the lamp as giving the greatest satisfaction, particularly in the 25-watt, 40-watt and 60-watt sizes. In the larger sizes with heavier filaments the spring support is still less necessary and in the 250-watt lamp practically all manufacturers employ a rigid support. For a time a center anchor was used in one make of 25-watt lamp but this is not now recommended, as the advantages expected are not borne out by experience.

I wish to call attention to a paper on "Tests of Tungsten Lamps", by T. H. Amrine and A. Guell, giving the results of observations on three types of lamps, two of German manufacture, the third American. The results in comparison with the two foreign lamps are very much in favor of the home product.

John W. Howell: There is one characteristic of the tungsten and carbon lamps which I have omitted to mention in this paper, and that is their relative candle-powers per unit of surface. We are all familiar with the intense brightness of the tungsten lamp, as compared with the old carbon filament, and we know that it is necessary to shade the direct light of the filament from our eyes, either by shades or frosted bulbs. As a matter of figures, the tungsten filament at its normal efficiency is giving twice as much light per unit of surface as the carbon filament at its normal efficiency. If the two lamps are placed at the same efficiency, the conditions reverse; the carbon filament is then giving twice as much light per unit of surface as the tungsten filament. This is an indication of one of the reasons of the efficiency of the tungsten lamp, because when you see a carbon lamp giving twice as much light per unit of surface as the tungsten lamp, there is a strong physical indication that the temperature of the carbon lamp is much higher than the temperature of the tungsten lamp, and it is a fact, at the same efficiency, a carbon lamp is much hotter than a tungsten lamp. When you examine the same characteristic for a tantalum lamp

it is interesting, because the normal efficiency of a tantalum lamp is two watts per candle, and at that efficiency the light per unit of surface is the same as the carbon lamp, at 3.1. This marked difference between tantalum and tungsten indicates one reason for the poorer efficiency of the tantalum lamp.

G. S. Merrill, M. D. Cooper, H. D. Blake (by letter): It is well known that tungsten filaments, due to their positive temperature coefficient take more current at the instant of starting than after they become heated. The engineering department of the National Electric Lamp Association recently conducted a series of experiments to determine whether this initial current rush has the effect of decreasing the life of the lamps. Three lots of tungsten sign lamps, 6 lamps in each lot, were placed on test—the first lot was burned continuously, the second lot was flashed 3 times per minute and the third lot was flashed 30 times per minute. It was found that there was a slight decrease in

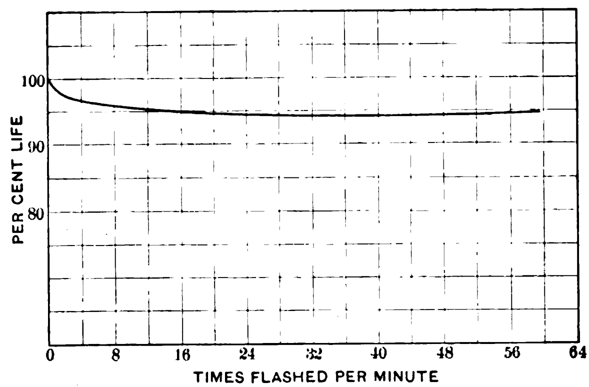


FIG. 1

life with the lamps that were flashed, but that this decrease was so slight as to be practically negligible. The curve of Fig. 1, plotted between frequency of flashing and the per cent of normal total life, shows a decrease of about 6 per cent in life up to 35 flashes per minute. For higher frequencies the life rises toward normal value. This test, due to the small number of lamps used, is not, of course, absolute proof that the initial current rush may not have a greater effect in decreasing the life, but it indicates that the effect is not as great as might be supposed.

That the above should be the effect becomes evident on consideration of the "cooling curves" given in Fig. 2. These curves show the per cent of cold resistance of tungsten lamps at various time intervals after the lamp has been turned off. If the lamp is allowed to cool completely before being again lighted, the initial current rush will be as severe as at the first lighting. If, however, it is turned on when the resistance is

still considerably above cold value, the current will not rise to as high an initial value. For instance, if a sign lamp is flashed six times per minute (5 seconds on, 5 seconds off), it will be re-lighted when the resistance is still $2\frac{1}{4}$ times the cold value. and as the hot resistance is about ten times the cold value, we would expect only about one-fourth as great a rush of current as when the lamp had fully cooled.

Flashing at very high frequencies would correspond to operation on alternating current, which would give the same life as when burned without interruptions.

Mr. Howell's mention of spring supports brings up the question of the adaptability of tungsten lamps to burning in a horizontal position. The complaint is sometimes made that tungsten lamps do not prove satisfactory when burned horizontally because the filaments sag.

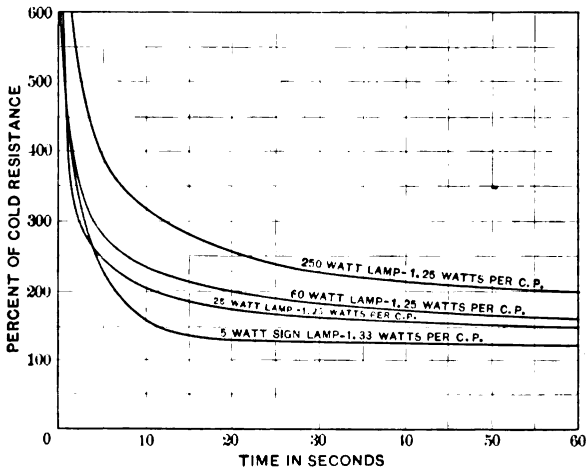


Fig. 2

The sagging filament in a horizontally burning lamp will conform closely to the catenary curve, for the filament is comparatively heavy and after continued heating will respond to the force of gravity nearly as well as a perfectly flexible string or chain.

The accompanying curves were derived on the assumption of this catenary curve. The equation of the catenary is:

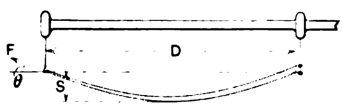


Fig. 3

$$y = \cosh x$$

and in this form the y intercept is 1. For a given distance, D, between supports, the sag will be

$$s = \cosh \frac{D}{2} - 1 \qquad (1)$$

$$\text{or the per cent sag} = \frac{100}{D}\ S = \frac{100\left(\cosh \frac{D}{2} - 1\right)}{D} \tag{2}$$

Fig. 3 shows in an exaggerated manner, the way in which a filament will droop and as there shown, D is only the distance between the ends of the freely sagging portion of the filament. Due to the rigid weld at the base, the whole filament will not sag freely, hence D will not be the whole of the distance between supports.

The slope of the curve will be

$$\frac{d\,y}{d\,x} = \sinh x$$

The angle θ, which the filament makes with the horizontal through the end of the freely sagging portion will be given by the equation,

$$\tan \theta = \frac{d\,y}{d\,x} = \sinh \frac{D}{2}$$

If the weight of the filament is W, the supporting force F will be given by

$$F = \frac{W}{\sin \theta}$$

from which

$$\frac{F}{W} = \frac{1}{\sin\ \tan^{-1}\ \cosh \frac{D}{2}} \tag{3}$$

Using the parametric equations (2) and (3), curve A of Fig. 4 was plotted, showing the "stress ratio", F/W, for any given sag.

When a lamp hangs vertically, the maximum force is equal to the weight of the filament, hence the above ratio is the same as the ratio between the filament stress when the lamp burns horizontally and that when it burns vertically.

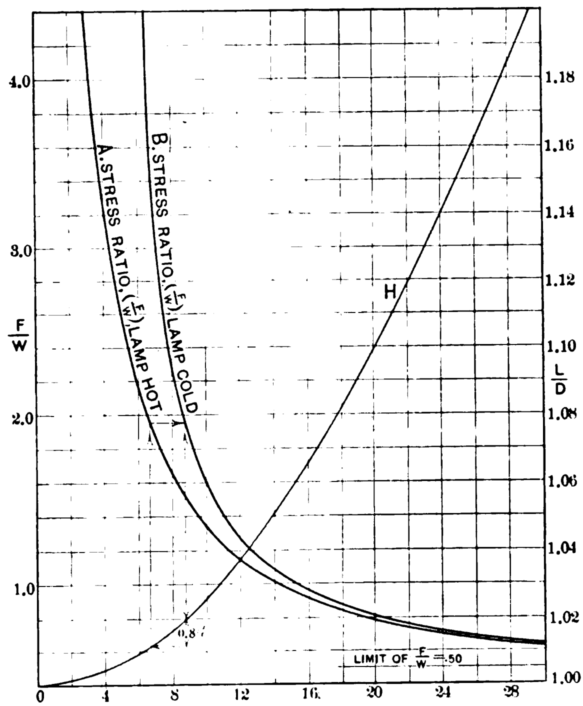
To investigate the effect of contraction on cooling, it is necessary to get some relation between length of filament and corresponding sag.

The total length L is given by the equation

$$L = 2\int_0^{\frac{D}{2}} \sqrt{1+\frac{d\,y^2}{d\,x}}\;d\,x$$

$$= 2\int_0^{\frac{D}{2}} \sqrt{1+\sinh^2 x}\;\;d\,x$$

$$L = 2\sinh\frac{D}{2} \qquad (4)$$



PER CENT SAG (S/D), LAMP HOT

FIG. 4

Using this equation in connection with (2), curve H was plotted showing the per cent sag for a given value of L, expressed as a percentage of D.

A point on curve A shows the stress in a horizontally burning filament for a given sag when the lamp is burning. At the same point, the ordinate or curve B shows to what extent this

stress is increased by the shrinkage of the filament on turning off the lamp. In deriving this second curve a shrinkage of 0.8 per cent was used, as determined by experiment. Curve B was derived from A as follows: For example, at 8.8 per cent, sag L is 102 per cent of D. On turning off the lamp, L decreases 0.8 per cent, hence the sag will be reduced to 6.8 per cent, corresponding to a stress ratio of 1.90, which is plotted over the "hot sag" of 8.8 per cent.

The curves show that a certain amount of sag is necessary if excessive filament stresses are to be avoided. If a lamp were so designed that when burning horizontally the filament would sag but 7 per cent, the stress would be 1.85 times as great as when burning vertically, and when turned off, the stress ratio would rise to 3.0.

The effect of burning a lamp is to cause the filament to disintegrate gradually. This disintegration, moreover, is not absolutely uniform, but is liable to localize at any weak points on the filament, if such there are. As the lamp continues to burn, the weak spots disintegrate more and more rapidly, till they can no longer withstand the imposed mechanical stress and a burnout results. It is therefore apparent that, although the filament as a whole could withstand a stress many times greater than its weight, yet, due to its non-uniform disintegration, an early burnout will be the inevitable result of insufficient sag and consequent high stress ratio.

A number of lamps, of the 25, 40 and 60-watt sizes and of the most recent design, showed from 10 to 15 per cent sag after they had burned for some time. The curves show that for this range of sag, the filament stress ratio, even when cold, will not rise above 1.60.

The curves cannot be rigorously applied to lamps larger than the 100 watt, for in these the filaments are larger and stiffer and do not sag freely.

The investigation of the flickering of incandescent lamps on alternating current can be separated into two divisions; first, the determination of the effect on the cyclic variation in candle-power produced by varying the size, length and material of the filament; and second, the determination of the relations between cyclic variation in candle-power, intensity of illumination, and "critical frequency" (or the frequency at which the sensation of flicker just disappears).

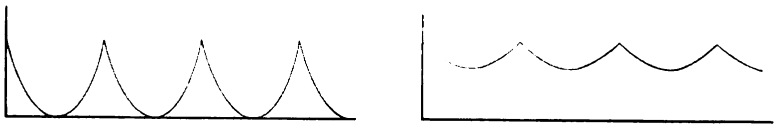
We have recently conducted some experimental work on the second division of the subject--the relation between cyclic candle power variation, illumination intensity and critical frequency. We found that for a cyclic variation M, equal to $\frac{\text{variation in c.p.}}{\text{max. c.p.}}$, and an illumination I, in foot candles, the critical flicker frequency f, in cycles per second (twice the current frequency) is given by the relation

$$f = 43\,(I\,M)^{0.13}$$

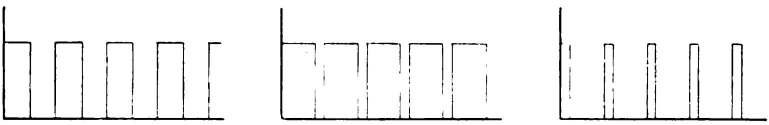
The constants in this equation were derived from five sets of data taken by two different observers, and the average deviation from the mean is about 7.8 per cent for each constant.

The cyclic variation in illumination was produced by a vane rotating at variable speed in a beam of light. In front of the vane was an opaque screen with a hole in it, the hole being covered with a ground glass diffusing plate. By using vanes of different sizes, we obtained different ratios of variable to maximum illumination. The flicker was viewed on the test plate of an illuminometer placed eight inches from the ground glass. Simultaneous readings were taken of the illumination and of the speed of the rotating vane at which the flicker sensation disappeared.

The rotating vane gives a cyclic variation in illumination about like the following curves:



Experiments show that the cyclic variation in candle-power of a lamp on alternating current very closely approximates a sine wave raised up above the axis. Dr. Kennelly conducted some experimental work on flicker using cyclic light waves of the following shapes, and his results tend to show that the critical



frequency is a function only of the maximum and minimum illumination, and is not affected by wave shape. His equations when put in the form expressed above, agree closely with ours. His results were published in the 1907 Proceedings of the National Electric Light Association.

The question of flicker comes up most often in connection with the operation of metal filament lamps on 25 cycle current. Letting f in the above equation be 50 (the flicker frequency corresponding to a current frequency of 25 cycles) there results

$$I/M = 3.18$$

The table below is computed from this equation and shows the maximum permissible cyclic variation in candle-power allowable with various intensities of illumination. If in any case the variation is greater than that given in the table, a flicker will be perceptible. With an illumination of less than

about 3 foot candles, flicker will not be discernible, no matter how great the cyclic variation.

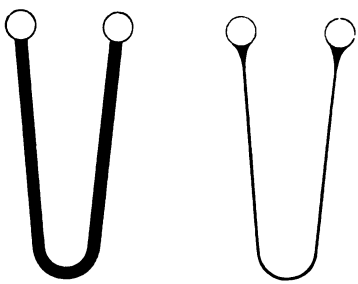
Intentisy of illumination I	Maximum allowable cyclic variation on 25-cycle current M
10	31.8%
8	49.8
6	53.0
5	63.6
4	79.5
3.18	100.0

We thoroughly agree with Mr. Howell in his statement that lamp testing is absolutely necessary to lamp making and also a very necessary adjunct to proper lamp using, but one should not understand from Mr. Howell's remarks that the necessity of testing in any case extends beyond the manufacturers or other thoroughly equipped lamp testing bureaus. Unless lamps are tested under the most rigid conditions the results are worse than useless and this applies with particular force to tests run at higher than normal efficiencies in order to shorten the time of testing. In such "forced" testing the effects of errors in test voltage are multiplied many times in reducing the results to normal performance and if the forcing is carried to an excessive point the extremely high temperature produced may create abnormal conditions which tend to make the lamps appear better or worse than tests at actual rated efficiencies would have indicated. Do not understand for a moment that we wish to undervalue the importance of forced testing, for when conducted under proper conditions and with proper knowledge of the limitations and errors to which it is subject, the forced test forms a very valuable means of rapidly attaining comparative results and has proved of inestimable service to the manufacturers. The Engineering Department of the National Electric Lamp Association has been devoting a great deal of study to the forced testing of metallic filament lamps, principally because the extremely long life attained at normal efficiencies served to severely tax the testing capacity and because urgent demand was being continually made by the factories for quicker test results. In spite of the fact that this problem has been before the engineers of the department for some time, no correction figures have yet been decided upon which can be regarded as final. Since Mr. Howell has brought the subject before you and as some may endeavor to proceed with forced tests upon the figures he has given, he will give some data in connection with this matter.

The earlier attempts to secure a correction figure for forced tests were based upon the average life of numerous lamps, run at various efficiencies. Tests conducted on such lines were not fruitful of results of the accuracy it was desired to attain. A study of the results of such tests, and previous experience with performance of the older and better known carbon filaments led to the following conclusions.

Steinmetz* has stated that "tungsten filaments do not ordinarily fail by evaporation as is the case with carbon, but by melting at some weak spot;" and also that "blackening of tungsten lamps is not gradual, as with carbon, but occurs simultaneously with impaired vacuum and appears rapidly." Our experience would indicate that there is a certain slight amount of normal blackening of tungsten lamps. The fact that this blackening deposit is found to consist largely of tungsten, and that the current after the initial rise tends to decrease gradually leads us to believe that the filament actually is vaporized to a limited extent.

A perfect filament would have a perfectly uniform temperature throughout practically its entire length. Near the supporting wires, the cooling effect due to these supports, would demand consideration. This filament could be conceived to be disintegrating at a uniform rate throughout its entire length except near the supports, with an ultimate result somewhat as shown in Fig. 5, which represents in an exaggerated way a short length of filament.



a b

FIG. 5

The candle-power of such a filament when burned at a constant normal voltage would probably show a slight initial rise due to changes in the physical characteristics of the filament material and to changes in the condition of the residual gases in the bulb (which of course are at extremely low pressure). After an initial rise the candle-power would drop gradually at a diminishing rate, until the radiation within the limits of the visible spectrum had become incapable of producing the sensation of light. During this period the value of the current flowing through the filament would have changed in a somewhat similar manner to the luminous radiation, but even after the filament had ceased to emit visible radiation the current would still flow and the filament would never burn out.

The decrease in candle-power would be due essentially to two things:

1. The temperature would decrease as the filament material evaporated and the diameter decreased. Neglecting possible changes in physical characteristics after the initial changes already noted, the energy expended in the filament would decrease as the square of the diameter of cross section. Obviously the surface of the filament would decrease directly as the diameter, so that as the filament evaporated the energy expended

* "Radiation, Light and Illumination" pp. 80, 81.

therein would decrease more rapidly than the radiating surface and the temperature would decrease.

2. The total radiating surface would be decreased. As a third, though secondary effect blackening of the bulb by condensation of evaporated filament material upon the interior surface would cause a decrease in candle-power of the lamp as a whole.

Such would be the performance of a filament without defect. In actual filaments defects exist and the magnitude of the defects is a variable quantity which follows to some extent the laws of probability for a given lot of lamps. For example, out of a large number of lamps started on life test under the same conditions, a few would probably fail rather early in life due to large defects or imperfections in the filament itself. As the burning continues the "mortality" rate would increase as the average size defects would begin to cause failures. Then with

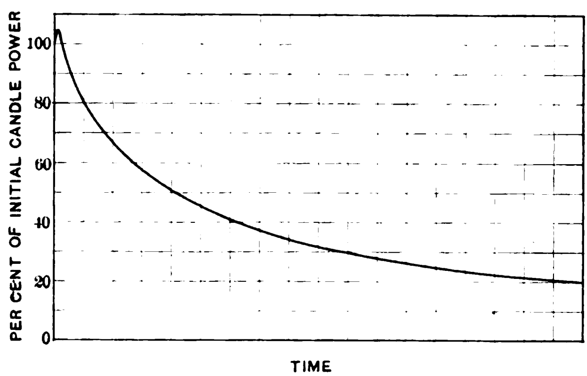


FIG. 6

the number of lamps burning considerably reduced, the rate of failure would decrease, for there would then be left only lamps having defects of less than average size. Finally there would be left only a few lamps which would give a very abnormal life, because they might happen to be particularly free from imperfections in structure. During this period the candle-power would have been undergoing the general changes previously noted which may be illustrated by the actual performance curve obtained from a test of 115, 16-c.p., 3.5-watts per c.p. carbon lamps as shown in Fig. 6. The average total life to burnout of the lamps represented on this test was several times the so-called "useful life", to 80 per cent of initial candle-power. The average candle-power corresponding to the average life gives us a means of judging the magnitude of physical imperfections which exist in the filament. On this basis it appears that at the present the carbon filament is more highly developed than

the tungsten filament, inasmuch as the carbon lamps reach a relatively lower candle-power value before failure than the tungsten lamps. This shows that there is still room for enormous improvement in the tungsten filament and that there are possibilities for obtaining still higher efficiencies than those at present attainable.

From the above considerations, it was decided that the correction figure to be applied to the life of metal filament lamps burning at other than normal efficiency could be determined more accurately from the time required by lamps operating at various efficiencies to reach the same percentages of initial candle-power or of initial current than from the actual time to failure or burnout. This should be true whether the changes in candle-power and current are due entirely to disintegration of the filament or whether they result from some other physical change which takes place during life.

It is manifestly impossible to obtain results on a single individual lamp at more than one efficiency, consequently for the purpose of arriving at the proper figure a special lot of lamps were made.

The following condensed report of the test on these lamps will be of interest in indicating what precautions have been taken in order to arrive at a proper correction factor for tungsten filament lamps.

Fifty 40-watt, 109-volt lamps were formed and assembled with the greatest possible care, in order to produce a lot of lamps which should be similar in all characteristic qualities. The work was started with over 1000 filaments from which 200 of the most perfect were selected after several rigid and careful inspections. Upon measuring the lamps made from these carefully prepared and selected filaments at 1.25 watts per c.p. the voltage with two exceptions was found to fall between 108.8 and 109.2 volts inclusive, a range of but 0.4 volts.* Aside from indicating a close selection, this uniform rating simplified to a large extent some of the work of testing, and has, we believe, eliminated the possible source of several small errors.

The test was divided into five sets of ten lamps, which were burned on 60-cycle alternating current at efficiencies of 1.25, 0.97, 0.85, 0.75 and 0.67 watts per mean horizontal candle

* If lamps can be made by commercial processes and in an ordinary factory which come within 0.2 of one per cent of the rating for which they were designed, it might be possible, by using more refined methods of manufacture, to produce a primary standard of light with tungsten filament.

An ordinary commercial lamp would not, of course, serve the purpose. It might, however, be possible to make a single loop lamp under rigid specifications as to size, length, and processes of manufacture of filament, dimensions of leading in wires, size and shape of bulb, etc., that could be exactly reproduced at any time. Such a lamp could be not only a primary standard, but an absolute standard as well, for it is well within the range of possibility to compute as well as measure the luminous intensity of such a source.

power respectively. According to the best correction figures available at the time the test was started each set was measured at approximately equivalent intervals. Readings were made with a contrast Lummer-Brodhun screen at rated voltage and

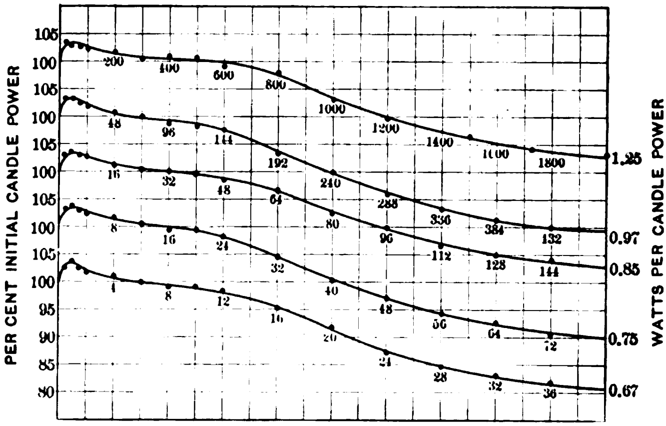


FIG. 7

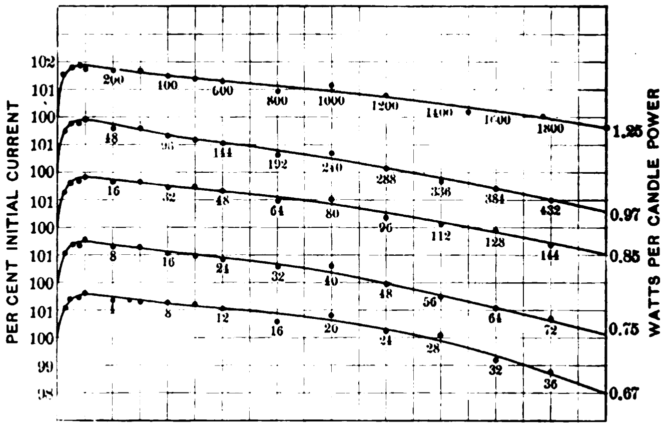


FIG. 8

all currents were checked in each instance with accurately calibrated standard laboratory meters.

Average candle-power curves for the various efficiencies, together with the actual hours burning, are plotted in Fig. 7, and average current curves for the same lamps are plotted in Fig. 8. We are able to show these only out to 2000 equivalent

hours, at 1.25 watts per c.p., because the test is still in progress with over 80 per cent of the lamps still burning.

We wish to call attention to the peculiar shape of the candle power curves of Fig. 7. Their peculiarity is the unexpected maintenance of candle-power during the interval corresponding to 300 to 700 hours on the 1.25 watts per c.p. curve.

We are at a loss for an explanation of this peculiar curve form but the accuracy of the timing and the photometry of the test leads us to believe that the results are correct.

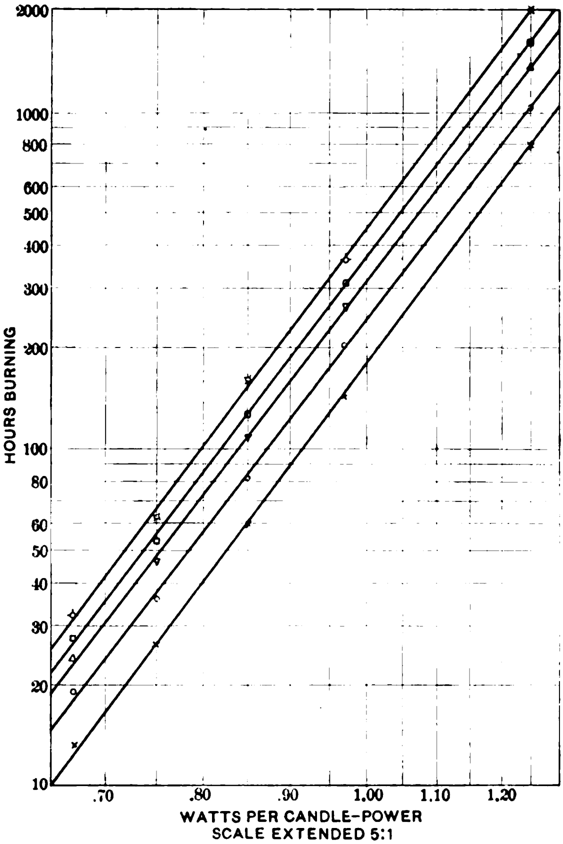


FIG. 9

From previous experience we assumed that the equation between life and efficiency is of parabolic form:

$$\frac{\text{Life}_1}{\text{Life}_2} = \left(\frac{\text{Watts per c.p.}_1}{\text{Watts per c.p.}_2}\right)^b$$

the object of this test being to determine the exponent b. In Fig. 9 and Fig. 10, we have shown several logarithmic graphs

between watts per c.p. and hours life obtained by comparing the interval of time required to reach various percentages of the initial values of candle-power and current. The results show that the life equations for tungsten lamps conform very rigidly to a pure parabolic law over the range investigated. The candle-power curves and the current curves appear to give slightly different values of exponent b. We believe that the

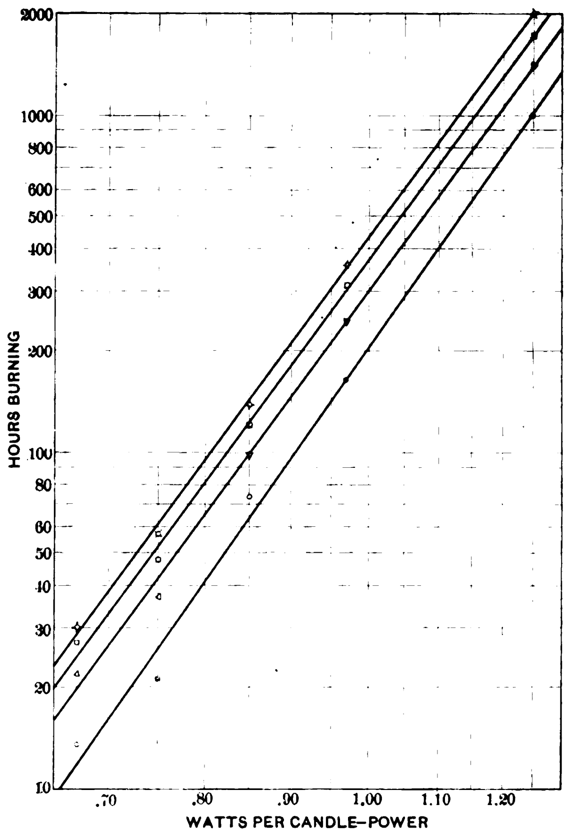


Fig. 10

exponent derived from the candle-power curves is the more accurate, where total life values are to be determined. In Fig. 11 we have shown curves between the watt per candle-power life exponent, b, and hours burning at normal efficiency (1.25 watts per c.p.).

The correction figure for tungsten filament lamps is still in some doubt, which may be evident from the results of the test previously described, and also from the fact that in his

paper Mr. Howell seems to have used two different values for the exponent of the life-efficiency equation. Mr. Howell states that the life was found to vary universally as the — 3.65 power of the candle-power. This exponent was derived from experiments on lamps with untreated bamboo filaments, but he says it was later found to hold for treated carbon and metal filament lamps. If the candle-power is taken to vary as the 1.75 power of the efficiency, as careful work would indicate, the exponent connecting the life and efficiency would be 6.4. From the life factors in the table given by Mr. Howell the value of the exponent through the normal working range is found to vary from 6.7 to 6.8.

In connection with the work we have done on forced testing of tungsten filament lamps, we might mention that a similar line of work is now being carried out on the tantalum filament lamps on both alternating current and direct current for a

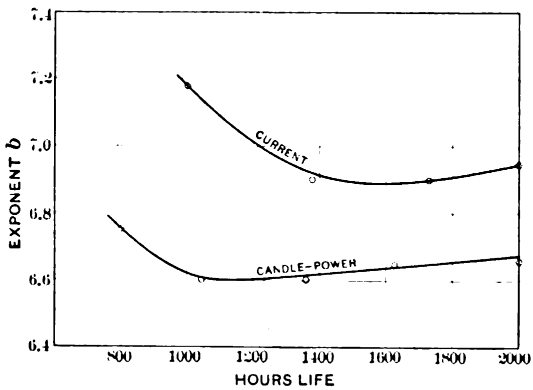


Fig. 11

similar purpose. Here interesting developments are expected on the alternating current, as from previous tests there is much to indicate that below a certain temperature the life is not affected greatly by the efficiency, being, we believe, more dependent upon the effect of frequency. However that may be, we will undoubtedly be in a position to throw considerable light upon the matter in the near future.

As to the relation between life and watts or watts per candle-power being very nearly the same for all different lamps we cannot agree. The exponent by which we express the relation between life and efficiency varies from 6.65 for the tungsten filament lamps to about 5.43 for untreated carbon. The first mentioned figure may be changed somewhat in view of later developments, but we find that the treated carbon, gem, and tantalum exponents, in so far as we have been able to determine them, are scattered between these limits.

In the table below are given our determinations of the exponents of the following equations, in which L = hours life, C = candle-power, W = total watts, e = watts per candle, V = voltage, I = current and R = resistance.

$$\frac{L_1}{L_2} = \left(\frac{C_2}{C_1}\right)^a = \left(\frac{e_1}{e_2}\right)^b \qquad \frac{C_1}{C_2} = \left(\frac{e_2}{e_1}\right)^h = \left(\frac{V_1}{V_2}\right)^k$$

$$\frac{W_1}{W_2} = \left(\frac{V_1}{V_2}\right)^n \quad \frac{V_1}{V_2} = \left(\frac{I_1}{I_2}\right)^x \quad \frac{R_1}{R_2} = \left(\frac{V_1}{V_2}\right)^q$$

Exponent	a	b	h	k	n	x	q
Tungsten	3.80	6.65	1.75	3.68	1.59	1.718	0.418
Tantalum	†*3.73	†*6.23	1.67	4.35	1.74	1.348	0.258
Gem	*3.7	*5.8	1.58	4.80	1.77	1.298	0.230
Treated carbon	3.65	5.83	1.59	5.55	2.07	0.930	-0.075
Untreated carbon	*3.62	*5.43	1.50	6.89	2.31	0.763	-0.310

(*) Computed from the dotted curve of Fig. 12.
(†) Direct current.

The values given for h, k, n, x, and q are correct within the limits of accuracy of photometers and electrical instruments, therefore are correct within 1 per cent. The values of a and b, however are subject to much greater error, probably at least 5 per cent.

In applying correction figures to forced tests, we have found the exponent b to be the most convenient one to use,.hence we call this the *fundamental* life exponent. The exponents k and x are also *fundamental* exponents, k being determined from photometric relations, and x from electrical relations. Given these three fundamental exponents, it is possible to determine the relation between *any* two of the variables, life, candle-power, watts, watts per candle, volts, current and resistance.

A curve plotted between x and k brings out some interesting considerations. As shown in Fig. 12, the points for all the lamps, except the gem fall on a very smooth curve. This is rather surprising, in view of the fact that the metal filaments exhibit more selective radiation than those made from carbon. The point shown in Fig. 12 for "old treated carbon" was obtained from performance curves of some treated carbon lamps which had burned for several thousand hours. The effect of this burning was to evaporate part of the graphitic layer deposited on the filaments in the treating process, or to partially "untreat" them. As could be anticipated, the point representing these lamps falls between those for treated and untreated lamps.

By using the curve of Fig. 12 it is possible to determine the

relation between any two of the variables, but the life (excepting for lamps of the gem class) when either of the fundamental exponents, k and x, is known. The exponent x of the voltage-current equation is obviously the easier of these two to determine, as it can be obtained from voltage and current measurements of a lamp.

It is within the range of possibilities that future experiments may give a smooth curve between x and one of the life exponents.

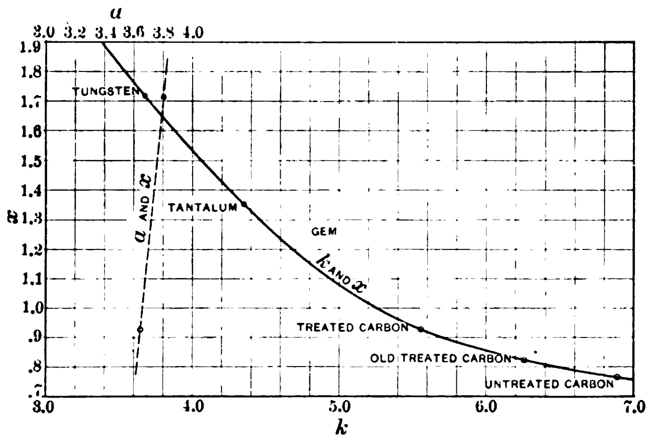


FIG. 12

If such proves to be the case, it will be possible to predetermine the *entire* performance of a lamp from its volt-ampere curve. The dotted curve of Fig. 12 is plotted between a and x. As only two points on this curve are known, it is drawn in as a straight line. Future developments may show that it has a slight curvature, but in the meantime it will serve as a good basis for calculations.

DISCUSSION ON "THE APPLICATION OF PORCELAIN TO STRAIN INSULATORS" AND "ELECTRIC RAILWAY CATENARY CONSTRUCTION", NEW YORK, MAY 27, 1910. (SEE PROCEEDINGS FOR JUNE, 1910).

(Subject to final revision for the Transactions.)

Percy H. Thomas: Mr. Kempton's paper gives us some actual tests on porcelain. We have had almost no data hitherto on the mechanical qualities of porcelain, quantitatively speaking. The manufacture of porcelain has been a secret, a mystery, and engineers have taken what was offered by the makers, taking the catalogues and selecting the best design for their purpose among those offered.

We here have a beginning of figures on the compressive, tension and other strength of porcelain as a material, some of the same sort of data as we have on steel and wood.

The compression strength of high grade porcelain is relatively very great, 16,000 lb. or thereabout. The average shearing stress here is given as 2400 lb. per sq. in., and the tensile strength as 650 lb.

This relationship between the various sorts of strength in this material dominates the form of design. We are very familiar with the shapes of insulators shown in the paper. There is one example among those of an important type of insulator in which is used the weakest quality of porcelain, and that is the suspension type of insulator, similar to Fig. 9 of the paper. This is a matter of which we should think pretty carefully.

I want to make a suggestion in connection with Fig. 9. That insulator shows porcelain in tension, as this design is made, and as the failure under test is described this insulator had better be made in some different proportion.

As shown in the paper we have a fracture at the bottom of the cap, that is across from the top of the inside pin to the bottom of the outside cap. The result is then only the tensile strength of the porcelain is utilized. If on the other hand, the insulator had been shaped differently, the pin being carried well up inside, with a deep metal cap taking hold well down on the insulator, since the pin cannot pull out without crushing the porcelain.

These tests, while they give some numerical figures are faulty in one particular. Mr. Kempton has apparently taken some insulators which he had at hand for making tests, and these show numerical results for those particular forms; but in no case are the tests such as to give us a clear knowledge of the materials as materials. Some of the insulators broke at the edge. In Fig. 3, the shearing test, there must be some tendency to split the insulator as shown; perhaps not much, but enough to render this data uncertain.

I remember some tests on one of these suspension types of strain insulators, such as No. 9, which gave a tension strain, roughly two or three times as great as Mr. Kempton has given. Possibly Mr. Kempton can say something on this subject at the end of the discussion.

There is another point which should be determined further by tests before any final conclusion is reached, and that is whether materials made by different manufacturers and materials of different compositions and treatment, will show the same unit of strength?

This would be an admirable thesis for some post-graduate work at a university or college. It is difficult for engineers in general practice to make a careful general study.

We seem in the matter of insulators to be arriving at the condition which finally comes in all new classes of work. At first designs are on the hit or miss principle but finally after sufficient investigation, reliance in made on a few of the old simple, practical, fundamental laws. For example, it is an old principle to take account of unequal expansion. The cementing in of metal pins in the strain insulator, may lead to trouble where expansion is serious. Again, if you do not allow for differences of flexibility in different materials, there is a strain on the porcelain. These matters are easily overlooked, but they are the simple principles that should have been borne in mind from the beginning.

It is often suggested that the way to get reliability in insulation, is to increase the margin of safety. This can be done quite easily in overhead railroad work where the trolley voltages are low; by choosing a factor of safety of five instead of perhaps three. This, however, is not very possible at 100,000 volts or even at 60,000 volts. Where feasible is thus possible to gain superiority and reliability at only small additional expense.

I ask Mr. Kempton a question: It is well established that a high tension porcelain insulator, 60,000-volt petticoat type, can be *shattered* by a lightning stroke without the puncture of the material, and without any arc following from the generator. This seems to be caused by something in the nature of a mechanical shock. The result is often the dropping off of the outer petticoat, it being broken close to the stem of the insulator.

I also ask Mr. Kempton if he has any suggestion to meet this condition. The phenomenon is reported at the Taylor's Falls system, and on the Ontario Power system. These are two thoroughly authentic instances. How can this strain be resisted?

Considering Mr. Smith's valuable paper, I would like to have his opinion as to the practicability of obtaining sparkless action in pantagraph trolleys by having a relatively light piece on the top of the pantagraph which shall have the least possible inertia. The heavy arms would then not be required to follow every slight movement of the sliding contact.

C. J. Hixson: It has been most interesting to have Mr. Smith trace the development of the catenary construction and listen to his comments and descriptions of the various devices used in connection with the same.

It has been stated that catenary construction was first brought

out in 1904. In 1903 while connected with the Allgemeine Elektricitats Gesellschaft, of Berlin I remember discussing and inspecting with visiting Westinghouse engineers, the catenary line installed by the Union Elektricitats Gesellschaft upon a branch of the State Railway known as the Nieder Schonweide-Spindlersfeld line. In October of the same year, the *Street Railway Journal* published an illustrated article describing the installation! I have no doubt Mr. Smith meant, that it was first used in this country at that time.

In Mr. Smith's comments regarding catenary developments abroad, and the improvements upon the New Haven System, as well as the experimental line of the Connecticut Company, he states there is a general feeling of satisfaction with these constructions. It is significant that all of these have a more or less flexible trolley wire.

This vertical flexibility of the trolley wire is, it seems to me, the keynote to the successful collection of current from a trolley wire.

The general conditions of stability and of sidewise anchorage, limit the vertical flexibility to a few inches, and it is necessary to assist this flexibility by frequent supports or hangers.

The height of the wave in the trolley wire as the collector passes along should be such as to take up all the sag between hangers and still raise the hanger a couple of inches as it passes under it.

The lifting of the hanger to a floating position eliminates the blow that would be delivered to a rigid support. Catenary hangers rigidly connected become increasingly hard as the bracket arm is approached. With a flexible hanger the increased and ever present flexibility at the point of contact, compensates in a measure for the inherent sluggishness of the roller pantagraph so complimentarally referred to in the latter part of Mr. Smith's paper.

For very heavy currents with two trolley wires side by side vertical flexibility is of great assistance in keeping the necessary contact pressure down to a modest figure and yet maintaining continuous contact with both wires at all times.

In order to have vertical flexibility the strain in the trolley wire should be moderate say from 1200 to 1500 lb. With this tension, with hangers 13 feet apart and with a No. 4/0 trolley wire, a vertical flexibility of an inch or so can be attained with an upward pressure of about 7 lb. This reduced tension in the trolley reduces the strain upon pull-offs, anchorages, strain insulators, and the line in general, thereby decreasing the original cost and the cost of maintenance.

In order to maintain the tension between reasonable limits at different temperatures provisions should be made for taking up the slack without disturbing the hangers and pull-offs.

The trolley wire is held best on curves by frequent pull-offs. This gives maximum flexibility with low stresses and moderately

strong strain insulators. On earlier installation steady braces were used, but they have now been superseded by either flexible pull-offs or line steadiers. A steady brace when used as a strut gives a hard spot in the trolley wire.

Regarding pole spacing on curves, the table given is, we assume, designed to be used with no other points of pull-off than a steady brace at each pole. It is possible to maintain this same offset of the trolley wire from the center of track and use a longer pole spacing by running a back bone and using more pull-offs. This also makes a more flexible construction. If the curve happens to be on the side away from the pole line, a bracket extension can be used to support the backbone.

In conclusion it might be said that a single messenger flexible catenary has been in successful operation for the past two years upon the Saratoga Division of the Schenectady Railway. There has been no sign of wearing the galvanizing on the messenger wire due to the movement of the loop, as the sides of the same seldon if ever more than just touch the messenger wire.

R. D. Coombs: Before attempting to say anything about the experiments made by the Pennsylvania Tunnel and Terminal Railroad about two years ago, I might call attention to a few general facts, or rather, general considerations.

Since the track on which the equipment runs is not a plane, but a series of vertical curves, I think that it is entirely unnecessary to attempt to keep the trolley wire perfectly horizontal. The equipment will not run in a plane, and so I cannot see why it is necessary to keep the trolley wire in a plane. That is aside from the fact that you cannot do it.

The question of flexibility is as yet very uncertain. The Germans have used a secondary catenary, and according to their statement it is entirely successful, but their speeds and train-loads are less than our own. The experiments to which I referred a moment ago seem to indicate that a single catenary with a very light hanger, composed of a flat section, $1\frac{1}{8}$ in. by $\frac{3}{16}$ in., looped over the messenger, and with the ordinary type of ear, was about as successful during the limited range of those experiments, as the German type with the auxiliary catenary. I am inclined to believe that a light hanger particularly in conjunction with a trolley wire having considerable stiffness and strength, possibly a steel trolley wire, as I believe was used on part of the New Haven installation, with either a copper messenger or copper feed wire to provide the necessary conductivity, would be a combination worth very careful investigation, and perhaps some experimentation.

The little hanger which loops over the secondary wire and attaches to the trolley wire, permits vertical movement, but seems to have a tendency to roll. On a portion of the experimental line, in putting up the trolley wire, it was found that the trolley wire had a twist or roll in it; and that the little hanger above the ear rolled laterally, and became to a certain extent,

bound, particularly at a pull-off. That same criticism, it seems to me, would apply to one of the figures in Mr. Smith's paper. I refer to Fig. 27. I should expect that inclined hanger, which is the same as a pull-off in effect, to roll, and I ask Mr. Smith whether that tendency has been experienced?

I am rather inclined to question whether it is necessary to pull the trolley wire to an excessive tension; and I believe that to be a subject which requires more investigation. I think the rigidity, and the tension of the trolley wire, the rigidity of the catenary above the trolley wire, and the flexibility or "intelligence" of the pantagraph should all be considered together; and that the failure of no one of them should be allowed to prejudice the particular arrangement of design.

Until these features are all brought into a harmonious relationship, no single arrangement can be termed saitsfactory. The pantagraph has always seemed to me to be a suitable field for experiments, and it should be noted that the secondary flapper, according to the statements of the German engineers, has given entire satisfaction abroad.

Director Freishmuth of one of the German companies, told me on his visit to this country about two years ago, that their auxiliary arrangement on top of the pantagraph, gave entire satisfaction, and that it did not spark. Their speeds are less than ours, and I believe their train-loads are also less; but if these pantagraphs have given the satisfaction abroad which it is claimed they have given, it would certainly seem that the pantagraph is a field for further experimentation and improvement.

Fig. 14 shows the messenger wire broken at each support, that is, each span, is a unit in itself, the advantage of which Mr. Smith questioned. I believe one reason is that the short span can be assembled on the ground, the hangers placed, and the end socket can be done either on the ground or in a convenient shop. It does not require an aerial operation.

The combination of the steel trolley wire and the copper messenger is in use on the New Haven and it was to be tried on the experimental line. It was not installed, but it was because of no lack of faith in it as a device. I believe the grease from the pantagraph shoes, or a system of greasing the trolley wire will prevent any rust.

The loop, attaching the hanger to the messenger wire, in case a loop is used, should be properly fitted at the top in order to allow the hanger to be vertical.

I do not think I can add anything in a very definite way, insofar as the results of the experimental line are concerned. It was necessary to put up comparatively short sections of different types of supports, different types of suspension, and different types of catenary. And as a result there was not a sufficient length of any one type to produce a determinative test. The locomotives passed rapidly from one section to another and it was almost impossible to ascertain on which section the

wear of the pantagraph shoe occurred. The relative wear could only be inferred by observation of the action of the pantagraph on a given section. At the same time it was possible by observing the action of the different types, to determine with more or less accuracy, a certain degree of relative merit.

The experiments did not continue through a round of seasonal changes, and definite results were not obtained, but I am inclined to question whether on long spans, there is any objecable action due to the tensional changes. The German construction, with the tension devices by which the wires are automatically kept at a certain tension by weights at the supports, were used, but no definite results were obtained. We obtained just as satisfactory service on sections where the device was not present.

R. C. Thurston: During a high wind and from the rolling of the car, unless the wires are in ideal condition, there is a good deal of slack wire, which will cause the trolley or the pantagraph to go to one side and dip, and while over, allow the ends of the shoe to hit the cross arm. If the wire was perfectly tight, this would not happen. When our road was first installed, we had no such trouble, but after the heat of summer and the cold of winter had expanded and contracted the wire, there was slack. But owing to the expense and the lack of time between trains, it is not always advisable to pull a slack wire tight.

The spacing rods are clamped tight to the messenger wires. I believe there should be a loop at the top of the spacing rod to allow the spacing rod to slide along the messenger wire, as the slack in the trolley wire would not then form the kinks in the trolley wire that it does now.

We have had several bad cases of brakes in the copper wire and the brake is not sudden, we found it to be an old fracture, which was probably caused by the pounding of the shoe. As these breaks do not occur in cold weather, it shows they were not from contraction of the wire through cold. The break is always formed after the car has passed over, and it always caused us to put a splice in the wire.

Chas. R. Harte: It is too often forgotten that the overhead construction of an electric railroad serves in two capacities.

As a conductor by which energy is transferred from the central station to the collecting device of the motor its function is simple and well understood; that it is also the track upon which the collector travels at high speed is a fact too frequently ignored, although it is in this latter capacity that practically all of the serious problems and difficulties arise.

In the case of a railroad, light rails laid on soft ground, where a marked displacement wave precedes the train, will, within their load capacity, give as smooth riding, and will require as little maintenance as the hundred pound rail on stone ballast as unyielding as possible. But if in either class of track there is permitted to occur a spot of opposite nature, so that there is

an abrupt change in the character of the displacement wave, there immediately follows rapid wear and serious injury.

Precisely the same results are manifested under similar conditions of the overhead; a hard point in an otherwise flexible line, or yielding spots in a rigid trolley at once develop kinks, crystallization occurs, and presently the wire breaks.

Up to the present time developments have indicated that the flexible line is easier of attainment than the rigid type; the writer believes, however, that the possibilities of the rigid construction have been by no means exhausted, and hopes to see further experiment in that direction.

The unfavorable condition is that in which whatever the cause, the trolley wire tends to bend on a short radius. In the earlier lines the comparatively large sag gave a large intersection angle at the points of support, and the clips being straight and short caused kinks in the line, in passing which the collector tended to momentarily reverse the bend on the approach side, and to deliver a sharp blow against the opposite side. The supposed necessity of eliminating the large sag led to the development of the catenary construction, as pointed out by the author. But, and this would seem to be the point urged by Mr. R. D. Coombs in his discussion of Mr. Smith's paper, a truly straight trolley wire is by no means a necessity. It is not the amount of the intersection angle at directional changes, but rather the shortness of radius of the enclosed curve that causes injury. With a long radius bend, and a type of support which would either gradually damp out the displacement wave or would transmit it without material interference, a heavily sagged trolley ought to give excellent service under severest conditions. Such a type of suspension, employing spans of two hundred and forty feet with a sag of thirty inches, the wire being carried in a curved ear of special design and some forty-four inches long, has been proposed by Mr. Joseph Mayer, Consulting Engineer (see Transactions American Society of Civil Engineers, Volume LXI, page 5) but so far as the writer is aware, has never been actually tried out.

The author, in describing double catenary construction says: "The excessive rigidity of this type has been found undesirable in practical operation". As an unconditional statement this is open to question. It is quite true that the first installation of this type to receive a thorough tryout was not entirely satisfactory, but the difficulty arose from the fact that while the hangers were very rigid, the line between yielded. At the critical speed the resultant chatter of the collector became synchronous with its period of vibration, and the line received severe punishment from the heavy blows of the pantagraph, in addition to the tendency to crystallization from bend reversals. The difficulty was most successfully overcome by duplexing the trolley, attaching the lower wire to the old trolley only at the centers of the secondary spans, but it is at least open to question if equally

good results would not have obtained had the line been made uniformly rigid by the use of a tee or similar stiff section attached to the hangers.

As pointed out by the author, the question of the side clearances of poles is very important on electrifications and particularly so on railroads with black signals. Eight feet from center of track to face of pole brings the latter practically in line with the signal mast in its usual position and the engineer or motorman is hedged by an apparently solid wall of poles, behind which except as it is very near, nothing can be seen. Certain types of signal employ a centrally pivoted blade, half being in front of the mast, to obviate this difficulty of sighting, but even for this, ten feet clearance from track center to face of pole is little enough.

The author's conclusion that the trolley wire should very closely follow the center line of the track will have the endorsement of practically all operating men, particularly if qualified by the further proposition that for wheel work the center of track is to be considered projected through the center line of the car, in order to meet the offsetting of the wheel by the super elevation of the rail. This same offsetting affects the lengths of brackets on curves particularly if the poles are on the outside, in which case the bracket bar will often have to be materially longer than the standard.

Operating men generally will further agree with Mr. Smith that the irregular and unavoidable cross motion of the shoe, due to various car movements and sways, entirely obviates the necessity—and most undesirable complication—of staggering the trolley wire to prevent localized wear on the collector.

To secure the desired alignment on curves the preference of the writer is with the method by bridle between poles, from which are taken equidistant pull offs. It is of course desirable to maintain this backbone dead, but on light curves the weight of the insulators is apt to cause sags which may prove troublesome. This can be helped by placing the insulators at the bridle, in which case of course the pull off itself is alive. In at least one instance the pull-off, of a single piece of seven strand steel rope, was unlayed for the proper distance, three strands going to the messenger, three to the trolley, while the seventh, whipped on the main portion, prevented further unlaying.

There seems to be little actual knowledge as to the comparative values of various types of catenary detail. In the matter of brackets the author expresses a preference for the three part pole collar as the method of attaching the over support rod to the pole. This is a point needing further investigation. The practice of passing the over support rod through a hole in the pole offers opportunity for decay to start, and weakens the pole slightly; on the other hand it has been the writer's experience that the pole collar, unless crushed into the pole, with consequent liability to decay troubles, is apt to slip and lower the

end of the bracket. The connection at the bracket end of the over support should also be positive; collars held by a set screw are prone to work loose and make trouble. As to bracket bar, the compound types offer greater attachment facilities, but are presumably more subject to corrosion. Devices at the pole end which permit lateral swing in case of unbalanced pull in the trolley save the bracket in case of heavy strain, as in the case of a broken wire, but the overhead is seriously slacked off for a number of poles each way; with rigid pole connection the brackets nearest the break are apt to be badly crippled if not ruined, but the area of disturbance is much less, a factor of great operating importance. The forms which split and take the pole between the members will stand very severe punishment from a trolley pole that has jumped the wire; socket pole connections, unless pinned or otherwise secured, are very apt to be shaken apart or broken under the same conditions.

As pointed out by the author, the matter of proper tension in the wire is complicated by the fact that conditions preventing excessive sag at high temperature result in very high stresses at low temperatures. How closely these stresses may approach the actual breaking strength of the wire is not always realized. Grooved 4/0 copper trolley is usually credited by the handbooks with a breaking strength of from 8000 to 8400 lb. A series of tests made by the writer, however on commercial stock samples gave a maximum of barely 7100 lb. on the unbrazed portion, with an average at brazes of 5600 lb., two samples failing below 5000 lb. (see Transactions, American Society of Civil Engineers Volume LX page 552).

While there are some differences as to detail commercial trolley wire is in general made from a " wire bar " of rectangular section, which is first rolled down to a round rod and then is finished by drawing. Brazing usually is done just before drawing, and in the samples tested it was evident that the latter treatment was not sufficient to overcome the local annealing at the surfaces of the braze.

The tension is properly dependent upon the nature of the overhead. If hangers are rigid the line between should be given equivalent vertical stiffness either by the form of cross section or by the tension; if hangers are yielding a much lower stress is permissible.

To secure an automatic adjustment the first Syracuse, Lake Shore, and Northern catenary had in the $\frac{7}{16}$-inch stranded steel messenger, at 20 deg. fahr. and for the standard span of three hundred feet, a sag of sixty-eight inches, but the trolley was a foot higher at the center of span than at the supporting bridges (see Transactions, American Society of Civil Engineers, Volume LX page 547). It was hoped this would minimize temperature troubles, but in the writers estimation its chief virtue lay in the fact that it materially stiffened the system against lateral sway. Later installations on this and allied lines have omitted this feature.

It is generally believed by users, that trolley wire could with advantage receive further treatment than is at present usual, for the market material of to-day certainly has decidedly less resistance to wear than the earlier output.

The writer is watching a working test of especially rolled wire which gives to 4/0 grooved copper an average breaking strength of practically 9000 lbs., but there has not elapsed sufficient time to permit any comment of value. The manufacturers, so far as the writer knows, have as yet set no commercial price on the treatment. Mr. T. H. Mather of the Syracuse Lake Shore, and Northern has for some time employed a wire which receives extra finishing treatment. The additional cost was, some time ago, about 6 per cent of the price of untreated wire; at that time Mr. Mather considered the resultant economy in maintenance and repair to be several times that figure.

But it is after all an illogical proceeding to impose the duty of resisting the abrasive action of the collector upon that member of the overhead which by nature is least adapted to resist wear, and functionally is most affected by loss of section, as is the case when the trolley wire is of copper. Phono electric and one or two other bronzes have for some time been used at points of unusually heavy wear, but the employment throughout of a trolley wire designed primarily to resist wear, as in the case of the Denver and Interurban's phono electric, and the New Haven's steel, is of very recent date. The author will doubtless be interested to know that his suggestion of a steel trolley and copper messenger has actually been in service for over a year. The trolley wire is identical in section with 4/0 grooved copper; the messenger is 19 strand bare copper wire cable sagged 24 inches for standard spans of 150 feet. This is on the experimental catenary section of the Connecticut Company's Hartford-Middletown line and the steel wire is continued for about half a mile beyond the catenary in simple suspension. At night the wheel has a bright tail of light but the actual wear in over a year's service is inappreciable, and this is also true of the messenger where it was feared the loops of the sliding hangers might cut the copper. This latter would indicate less danger to galvanizing on a steel messenger from sliding hangers than has been anticipated by some.

The Connecticut Company's experimental catenary has not had long enough service for final deductions as to the most desirable type of hangers, but indications to date seem to point to the old mechanical screw clamp ear with light hanger rod rigidly fastened to the ear, and looped over the messenger. The screws should be long enough to head up after the trolley is gripped; if this is properly done the type is at least as efficient as the more elaborate forms, and is far simpler. In this connection the author expresses a preference for " a nut screwing down on the lower end of the hanger rod, as in figure 24 as it can then never work off ". In the writer's experience, while the nut

cannot escape, it has been found necessary for such types of hangers to be fitted with a locknut, as otherwise the main nut backs up to the rod enough to loosen the clamp and permit serious wear.

Rigid hangers require high trolley tension, and in case of relative movement of trolley and messenger are apt to come to grief; hinged types if jointed top and bottom and rigidly gripped to messenger allow relative movement and give a little flexibility that hardly seems commensurate with the complication. Bottom slide hangers seem unduly subject to wear, but have the marked advantage that the parts lifted are all of equal weight. The foreign sliding hanger lines have a secondary messenger of very slight sag and the loop hangers are all of equal length and weight; that satistactory results were not obtained on certain American lines where hangers varied in length from four to twenty inches is hardly surprising. Long loop-hangers hinged at the ear have a tendency to tip when lifted, and sliding down the messenger lose their characteristic feature, and as a result of the shortened effective length, pick up the trolley.

Hangers with jaws closing symmetrically with reference to the rod will, within the limits of their capacity, take various wire sizes equally well; hangers in which the jaws do not so move however, while they have a small range, do not work well on sizes other than the one for which they were designed. For shoe work the contour of the jaws is of less importance; for wheel work it is essential that the jaws give good clearance lines, or, particularly on curves they will be badly pounded.

The matter of hanger spacing is one on which is needed much practical information—in fact this need of much practical information is characteristic of the entire subject of overhead construction. On a forty-mile-per-hour installation for wheel operation, with main spans of one hundred and fifty feet, excellent results are being had with a secondary spacing of ten feet, and barely twenty miles away equally good results are obtained on an installation identical except that the secondary spacing is fifty feet. It is the general impression that for shoe work the secondary spans should be very short; the writer knows of no installation on which long secondaries have actually been tried out, but it would seem that the manifest economy, if the number of hangers can be materially reduced without impairing the efficiency, warrants careful investigation.

The author touches a point of great importance in construction in the matter of hanger rod lengths for various spans. Theoretically the sag of each span should be mathematically exact; practically unavoidable variations occur to an extent which warrants the small amount of "fudging" which may be necessary to adopt standard span hangers to the shorter spans. The importance of reducing to a minimum the labor and the chance of error on the tower cars is best appreciated after a practical experience. In electrifying an operating steam road

the work trains lose from fifty to seventy-five per cent of their actual time, the lower figure being reached only under very favorable conditions; with much traffic on the line the time lost dodging trains may easily exceed the seventy-five per cent.

The author's point that strain insulators should under mechanical and electrical stress at the same time, is well taken, particularly where the strains are of the compression type where movement of the parts which in no ways affects the mechanical strength--in some cases actually increase it, due to better seating of parts--may completely destroy the insulating-properties.

The difficulty of securing good strain insulators for high voltage work makes desirable the suspended bracket construction similar to that on the Rochester Terminal, and which employs a standard line insulator, in spite of the fact that its weight and area are decided draw backs, particularly in sections subject to sleet.

The author's hope that further investigations will be made in regard to roller types of collar will be shared by all who have investigated the subject and it is by no means impossible that a modification of the present form of trolley wheel may be of much value. The writer has for some time had in mind a shoe design in which the main pantagraph movement ranging through several feet should be effected by some positive mechanical device, probably a pneumatic cylinder, the air supply to be controlled by a sensitive contactor mounted on the main pantagraph. This contactor, having little inertia and therefore able to follow the wire almost instantly, would take care of variations within its range of about one foot each side of the middle point. The valves operating the main traversing device would open as soon as the contactor passed this mid point, and in most instances the response would be sufficiently rapid to keep the movements of the contactor within its limits. If, however, the depression or raise of the wire was so rapid that the main device did not attain the speed at which the change was occurring before the contactor reached its outer limit the conditions would be no different from those which at present obtain a very material portion of the time; on too rapid raise there would be an actual break in the contact; on too rapid depression the main traverse would be forced down by the overhead until its acceleration was equal to the rate of drop in the line.

Ralph D. Mershon: The paper says that porcelain " can be moulded and worked into almost any desired form or size " This does not agree with my experience. I have designed insulators from time to time and endeavored to have them made out of porcelain. In some cases I have succeeded in having them made, and in some I have not. Not infrequently, where I did succeed, the price was prohibitive. As the result of the experience gained from such work in connection with a number of the insulator manufacturers of this country, I should say that porcelain, for insulators at least, can be practically moulded and worked into very few forms of limited size. The present

practical limit in thickness of porcelain of high dielectric strength is about ⅝ in. In some cases it is possible to get thicknesses of ¾ in. of high dielectric strength, but such pieces are usually produced at very considerable expense, and their production is uncertain.

The author's investigations of the physical properties of porcelain are interesting, but might, with advantage, have been carried a good deal further. The procelain he tested could hardly have been of the best quality as regards mechanical strength. The highest grade high-voltage porcelain made in this country will show a tensile strength of from 1,500 to 2,000 lb. per sq. in and a compressive strength of approximately ten times this. These figures are the result of a great many tests made by myself and by others.

Of course, ceramic materials of all degrees of strength less than this are met with, but it is also possible to obtain material of greater strength. I have tested ceramic material which ran as high as 2,400 lb. per sq. in. As it happened, however, this material was not the highest grade high-voltage porcelain. It was not vitrified throughout, if it was vitrified at all. The fracture showed fissures, and in general its appearance was such as to lead one to think it would have a very low tensile strength.

There is a great deal of work to be done yet in connection with ceramic materials for electrical work, and undoubtedly room for great improvement. It is extremely desirable to determine the conditions which affect the mechanical strength of such material, especially the tensile strength. Some investigations I have made seem to indicate that it is possible for porcelain to have a grain, something almost of the nature of a fibre, such as we find in wood or wrought iron.

A great deal depends, with different mixes, upon the amount of moisture present when the piece is formed, and whether the piece be formed by pressing or by the plastic method. It would appear, also, that, with some porcelain mixes at least, the degree of firing has a great deal to do with the strength. In some cases it would appear that a temperature considerably below that at which the mixture will vitrify, of even begin to vitrify, will result in greater tensile strength than if the heat be carried higher.

My investigations have been confined to American porcelains. Apparently some of the European porcelains run a great deal higher in mechanical strength. In the discussion of a paper recently presented before the Institution of Electrical Engineers at Manchester, England, Professor A. Schwarz gives the results of some tests he made upon porcelain. The tensile strength ran from 3,316 lb. per sq. in., for a rectangular test piece with a section of 0.2 sq. in., down to about 2000 lb. per sq. in., for a rectangular piece of 0.6 sq. in. in section. He found a compressive strength of 10,000 lb. per sq. in., for a cylinder two in. long by two in. in diameter; 40,000 lb. per sq. in. for a

cylinder one in. in diameter, and 52,600 lb. per sq. in. for a cylinder $\frac{7}{16}$ in. in diameter. He ascribes the lesser strength in the larger pieces to lack of heat penetration in firing, but I think it not unlikely that the apparent fibrous structure mentioned above had also a considerable amount of influence, especially if the cylinders were formed from plastic clay. It is evident that with such formation, the smaller the cylinder, the greater the proportion of its bulk that will partake of a fibrous structure.

In this matter of comparing strengths of different samples of porcelain, we, in our present ignorance, assume that all porcelain is alike. Such comparisons are about as logical as to compare tests made on high grade steel and tests made on the poorest quality of cast iron. Until this whole subject is given a more thorough study, we shall have no intelligent basis on which to compare results obtained at different times and with materials obtained from different sources.

O. S. Lyford, Jr.: The ideal conductor for the distribution of electric power for heavy railway operation is one that is either absolutely flexible or absolutely rigid, and parallel to the running rails. For low voltage work, which in heavy service involves the collection of large currents, the tendency is towards the rigid conductor, as characterized by the third rail. For high voltage work and consequent low current the tendency is towards absolute flexibility of structure and catenary trolley construction has been the best development thus far. Improvements in third rail construction have been in the direction of greater rigidity and improvements in catenary construction towards greater flexibility.

For intermediate voltages, it remains to be seen that construction will prevail and neither of these two, as now developed, is entirely suitable. For instance in the 1200 volt direct current system the currents are high for heavy railway operation. A locomotive such as recently adopted by one of the large railroads with motors capable of developing 4,000 h.p. in starting, the maximum current at 1200 volts would be 2800 amperes and the running current for maximum weight of train 1250 amperes. A suitable conductor for distribution of current to such locomotives must necessarily be heavy and the logical development is in the direction of rigidity of construction. This means either the perfection of a safe 1200 volt insulation for third rail or the development of a rigid overhead structure. The latter will necessarily be a very heavy and expensive construction and one open to many objections from the point of view of railway operation and maintenance. The former is possible, and is already being tried out, but if designed for usual railway clearances it will necessarily be cramped.

The two papers presented to-night relate to materials and apparatus for light structures with moderate stresses and therefore apply more particularly to constructions approaching

absolute flexibility. The discussion should be considered from that point of view.

Referring first to Mr. Kempton's paper, the tests reported verify the conclusion that porcelain used in compression is suitable for such strains as are likely to occur with a flexible and comparatively light overhead system. Referring to the question raised in the paper as to whether mechanical stresses weaken the porcelain stock electrically and therefore whether the combined mechanical and electrical test is necessary, it is the writer's belief that Mr. Kempton has arrived at the answer in the following statement:

"It was thought probable that the high stress in the section of porcelain under the load opened up slight flaws in the stock, rather than causing the sound porcelain to puncture below its unstrained puncture voltage."

It is possible that if the compression were applied to the insulator stock in such a manner as to absolutely distribute the pressure uniformly, there would be no evidence that a mechanical stress within the breaking limit weakened the insulator electrically. As a matter of fact, insulators of the style illustrated by Fig. 9 of Mr. Kempton's paper are subjected to a fairly uniform and not very heavy unit stress this being in tension.

With the various forms of insulators for use in compression, however, the stress is not distributed uniformly, as the metal parts are are necessarily elastic. For instance, in the double spool strain insulator illustrated by Fig. 29 of Mr. Smith's paper, there is necessarily some irregularity in the application of the mechanical stress to the porcelain. This difficulty also exists with the "loop" or "fish-tail" type of insulators. It was in the testing of these two types of strain insulators that we found it necessary to apply mechanical and electrical stresses simultaneously to determine the true safe limits of the insulator. It is the writers belief that after sufficient experience with a strain insulator of a given form it will not be necessary to make the combined tests on every insulator, but in this catenary work for heavy electric traction, which will usually have to be erected over a line already in operation, any reasonable expense in testing which will avoid replacement of insulators in the completed structure will ordinarily be found justifiable.

Referring to Mr. Smith's paper, the following comments are offered.

Poles and Bridges. There is still room for the development of a light form of pole to take the place of wood. One of the principal criticisms which maintenance-of-way officials make to the electrification with overhead trolley system is the danger to persons and property in the case of a derailment or collision which may result in overthrowing the overhead structure. It has been found that with wooden poles supporting a strong catenary structure, a derailment will result in cutting away the pole without bringing down the conductors. Heavy bridge work or heavy steel pole structures will not act as satisfactorily in such accidents.

Messenger and Trolley Wires. Mr. Smith refers to the use of a dynamometer in the rection of the messenger and trolley wires. Such practice was at first viewed with scorn by the superintendent who handled the Denver & Interurban work, and he has had very extensive experience in the construction of trolley work and transmission lines. Before the job was completed, however, this superintendent was enthusiastic over the results obtained, as he found time was actually saved and the structure when complete required very little readjustment and this only during construction and not after operation was begun. Since we left the job it has not been necessary to take out any slack or make material readjustments. This seems to prove also that the tension used, namely from 2000 to 5000 pounds, depending on the temperature, is entirely practicable and produces good results.

Use of Tension Devices for Trolley Wire. There was a question in the writer's mind as to whether the success of these devices in Europe was not due to the fact that the current collector used is very light and flexible. Such collectors are practicable in Europe where train speeds are relatively low, the variations in height of trolley are relatively small and currents collected are relatively low compared to American practice, but with the service which we are called upon to operate in this country such forms of pantagraph have thus far proved impracticable. With the American form of pantagraph shoe a pressure of at least 14 lb. seems to be necessary. Such shoes were tested out on the Pennsylvania R.R. test track and the writer watched their operation closely on the German form of catenary and compared this operation with operation on German roads previously inspected. The results, in so far as they could be noted with the brief tests on the short section of track, indicated that the American form of shoe will work as well as the European form, although this is quite contrary to the expectation of European engineers. It is the writer's belief that the success of this combination will depend on the ability to eliminate hard spots from the line. This seems possible at practically all points where high speeds are necessary.

Referring to Mr. Coomb's report that in the Pennsylvania R.R. test a form of catenary construction with one messenger and one conducting wire, the latter being supported with thin flexible hangers, gave as good results as operation on the German type of construction—this presumably relates to the action of the pantagraph shoe on the two types of conductor support, and seems reasonable to expect, as the flexibility of the simple construction is practically a great as that of the German construction provided there is sufficient distance between the messenger and the trolley wire so that the hangers are at all points long enough to be flexible. One question in relation to such a construction can be determined only by a test extending over a considerable time. This is the life of the flexible hangers. The oldest catenary trolley road in operation is that of the Stubaital

bahn line at Insbruch. On this line a simple catenary is used and the hangers are of galvanized iron wire, apparently about No. 12 in size. The writer inspected this line about two years ago and noted that many of these hangers were broken, apparently due to the vibration of the trolley wire. Such breakage will not occur with the heavier forms of trolley hangers described in Mr. Smith's paper.

Referring to the European construction mentioned by Mr. Smith, it is the writer's understanding that this construction was developed by the Allgemeine Electricitats Gasellshaft to obviate the necessity of tension devices used in the Siemens-Schuckert construction. It was believed with the use of an equalizer such as is illustrated in Fig. 16, the expansions and contractions in a catenary structure due to changes of temperature would be taken care of satisfactorily, without any other adjustment.

Catenary Hangers. Referring to the various forms of catenary hanger illustrated, one point which should be looked out for is that the hangers shall not damage the galvanizing of the messenger cable. This cable is an expensive item of the catenary structure and one hard to replace without delay to the traffic. It is therefore important that the life of the cable shall be as long as possible and to this end the galvanizing should remain intact. A form of hanger which has a flat loop over the messenger wire is therefore safer than a sister hook construction or any other form in which the cable may be more or less cramped. As Mr. Thurston pointed out, the design of the loop over the messenger should be such that the hanger can be moved along the messenger easily.

Steady Strain Device. Referring to the device illustrated in Fig. 28, of Mr Smith's paper, attention is called to the fact that the brace between the trolley wire and insulator is so short that without material change in the length of the bracket it is possible to place the steady strain insulator on either side of the main insulator and therefore always have the steady strain in tension. On other words, it is not necessary to use the steady strain as a strut which may produce a hard spot, as suggested by one of the speakers.

Strain Insulators. Mr. Smith makes a very good point regarding the disc type of insulator as follows:

> " An excellent point about the disc type of insulator when used within its capacity is that there is a mechanical linkage of the guy cables on opposite sides of it, which prevents their falling apart if the porcelain breaks."

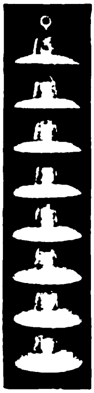
This feature should be incorporated in all strain insulator construction. It exists in the double spool strain insulator illustrated in Fig. 29 of Mr. Smith's paper. It cannot, however, be incorporated in such wood strain insulators as now employed and this is one of the principal objections to the use of wood, as either burning or breaking of the wood will throw the overhead structure out of alignment and possibly drop it.

W. H. Kempton: In speaking of porcelain and its quality, I do not want to give the impression that I do not have faith in it, but rather that I realize its limitations. All companies making high-voltage insulators, have developed the material to such a point that it is quite reliable; and while there is still room for improvement in porcelain insulators, and while many companies are trying to improve their quality and get more uniform results, still I think it is well to admit just how reliable porcelain is, and use that information in our designs. In that way we will avoid over-confidence, and thus get a design which will not break down in service.

Regarding Fig. 9 of the paper, I regret that I did not fully explain in the original paper that this is not a commercial insulator. It was made for the deliberate purpose of getting what Mr. Thomas points out; a pure tension stress for the purpose of a combined mechanical and electrical test.

As a matter of fact, the company with which I am connected manufactures large quantities of insulators along the line Mr. Thomas suggested: that is with the pin extended far up into the head and cemented in. We have made them with a mechanical strength of over 15,000 lb. That form was not touched on in this paper, as it is used as a suspension insulator. I did not expect to include that form of insulator in the discussion, and so avoided bringing the matter up.

Referring to the other question, regarding the protection of the insulator, I personally am convinced that the breaking of the petticoats on the insulators he described, was not due directly to electrical stresses. I have punctured many insulators and have yet to find one that broke, except under mechanical strain, or due to the heat from the arc. It is possible in the instance he described, that it was first punctured, and the heat from the following arc concentrated on that spot on the insulator, caused it to burst.



Another explanation might be added although it is rather far-fetched, and I do not think is correct; that is, that type of insulator has considerable capacity, and due to the high frequency of the lightning, it is possible there would be a marked vibration of the porcelain. But I do not think it possible to get sufficient vibration to shatter the porcelain.

The large disks of porcelain, as now manufactured, are pretty tough and I think it was the heat from the arc in the case cited, that broke the insulator. I have had them fail in a very similar manner in actual tests.

Assuming however that the insulators were broken directly by stresses due to the lightning, a remedy would be the use of suspension insulators made up of a number of units. One or more of these units might be broken without disabling the line, but I do not think it possible for all of them to be broken in that way.

The accompanying cut shows a suspension insulator made up

of eight units. Of course, the insulator may be made up of the proper number of units to suit the voltage of the line. Each of these units is ten inches in diameter and has dry flash-over voltage of 90,000 volts.

Replying to Mr. Mershon's comments, I think his statements in a measure verify my claims. As pointed out in my paper, the samples used were made without any attempt to secure extra good quality. The figures given are such that they may be used for design work with safety. As pointed out, especially prepared samples can be made with the same mixture and carefully burned and much higher results be obtained. Such samples are always made with uniform section and comparatively small. I have made tests with very much higher results, but did not give these figures for the reason that if they were used in a design, the insulator would fail to come up to the expectations of the engineer, and the manufacturer would be discredited as also would porcelain as an insulating material having mechanical strength.

Bronze is a parallel case. Government experiments show that bronze can be made with a tensile strength of 100,000 pounds per sq. in. and over, but practical foundrymen will decline to guarantee over 50,000 lb. to 60,000 lb. per sq. in.

It would be interesting to know if the dielectric strength of the samples made by Professor Schwarz was as good as the best American product. The two qualities must be worked out together. High tensile strength can be had at the expense of dielectric strength.

Mr. Mershon's criticism of my statement regarding the range of porcelain manufacture is in a measure merited. When it is considered that high voltage material must be moulded in a plastic state, dried, and then burned at a temperature that renders it pliable, it will be seen that it is difficult to make beyond a certain size and that the shape must facilltate moulding and drying the clay.

Referring to the " grain " noted by Mr. Mershon, it might be said that it is practically impossible to mould wet clay into insulator forms without its having a more or less marked fibrous structure. It might also be added that, to the best of the writer's knowledge, it is impossible to make high voltage porcelain by the " dry press " process. In the wet process, the clay is mixed with water to a plastic state when all air can be removed from the body. When the clay dries, it leaves a dense close grained body. In the " dry " process, the clay is ground up dry and made moist enough to make it retain its shape when pressed in a mould. Mechanical pressure is depended upon to make the body compact, and experience has proven that a sufficiently dense body cannot be obtained in this way for high voltage work.

There are one or two points I should like to speak of in connection with Mr. Smith's paper: one is in regard to the length of the brackets for a spacing of eight feet between the center of

the track and the center of the pole. From a rather uncomfortable experience, I found it was necessary to use a longer bracket on curves than on tangent, when the poles were placed on the outside of the curve. This is due to the rake of the pole in one direction, and the elevation of the track in the other. With these conditions it is necessary to use extra long brackets on curves, or longer ones everywhere.

Mr. Smith speaks of lining up trolley wires on the curves when pantograph trolleys are used I think it is unwise to allow as much deviation from the center line on curves as was the practice at the beginning There are four considerations to be borne in mind in this connection. One is the rake of the pole; two, the elevation of the outer rail; three, the speed; four, the play of the bolsters on the car.

At standstill or at slow speed on curves the pantagraph trolley tends to swing toward the inside of the curve; but when running round the curve at 40 miles an hour, the momentum of the car throws it over on the bolsters toward the outside of the curve so that there is a difference of from 10 to 12 in. in the position of the trolley with respect to the wire. In one case, the line had been constructed very carefully; but in spite of that the pantagraph trolley would swing out free from the trolley wire and pull down some of the line or pull the trolley from the car. It looked impossible from measurements on the line until we discovered that the construction of the car allowed it to swing over on the bolsters when going around the curve at high speed, sufficient to throw the pantagraph clear of the trolley wire. The remedy in that case was to re-line-up the trolley wire and add more poles or pull-offs where necessary to reduce the offset of the trolley wire and then fix up the car to avoid such excessive swaying

This is one of the personal experiences I have had emphasizing the care that must be exercised in the erecting of a trolley line on which pantagraph trolleys are to be used.

W. N. Smith: The remarks of those who have joined in the discussion quite generally agree as to the fundamental principles underlying catenary construction.

As was stated by the Chairman, the overhead line still offers a great number of unsolved problems. Fortunately they are of a type capable of being attacked by the protession at large. Comparatively few electrical railway engineers have been trained as designers in electrical factories, and those who have not can hardly approach the problems of motor design at the point where the most of our alternating current railway discussions begin. Intricate theories of motor design require a mathematical ability which is not so well distributed amongst engineers generally as is the plain good sense which must underlie the planning and execution of every large undertaking in railway electrification. Problems of overhead construction, and of the equipment related thereto, are mostly mechanical, and are thus

open for solution to engineers generally on a broader and more liberal basis than is usually embraced in the commercial or manufacturing point of view—as has been indicated this evening.

Taking up the various comments in their order, it seems to me that Mr. Coombs answered Mr. Thomas's question in respect to the secondary arm or tip which has sometimes been employed at the top of the main pantagraph. This device has been used on the Simplon tunnel locomotives with sliding shoe on the tip. The Simplon locomotives travel with a maximum speed of 45 miles per hour and the contact shoes are of the sliding type. Even with the lessened inertia of this device, the shoes only last about 1700 miles.

It is true that my references to the beginnings of catenary construction applied only to its use in this country, as there has not been very much evidence that at the time of its introduction in America, our practice was influenced particularly by European methods.

Mr. Hixon's reference to wave action brings out a fundamental principle underlying successful catenary construction and operation where circumstances are favorable; that is to say, I believe that the best results will be obtained when wave action, as referred to by Mr. Hixon, is recognized and provided for. This depends very largely on the construction of hanger employed, and only experience can demonstrate which type of yielding or floating trolley hanger is really the best. The experiments mentioned by Mr. Hixon and Mr. Harte will doubtless help in determining this exceedingly important matter.

The fact that the old pole and wheel trolley operates so well with trolley wires having considerable sag, illustrates the importance of recognizing wave action, which is so much in evidence with the wheel type trolley; and this confirms my belief that the natural and desirable wave action in the trolley wire will be very much helped by the roller pantograph, and with less wear and tear than with the sliding pantograph. This point of view is based upon the probability that the heavy work of the future will be at high tensions, *i. e.*, at 11,000 volts or higher, and that the trolley pole and the narrow grooved wheel accompanying it will not be regarded as thoroughly reliable for high speed operation under steam railroad conditions, so that it will be necessary to have a transverse rolling or sliding contact which will not leave the wire under any circumstances and which the motorman or the train conductor will not be obliged to regard as an extra source of responsibility or worry. The problem becomes then one of flexible operation at high speed with a transverse contact device, and it is quite evident that the successful operation of such a combination will be met only by recognizing and providing for a vertical wave action in the trolley line.

Mr. Coombs reminds us of the fact, commonly overlooked

that the railroad track itself is not a plane surface as it is usually considered to be, and that the train itself makes a wave action in the rails as it runs over the track. This emphasizes the necessity for directing our efforts towards upward flexibility in the trolley wire, rather than to smoothness without flexibility.

With respect to the possible twisting in the compound catenary construction, illustrated in Fig. 27, as apprehended by Mr. Coombs; it would seem to me that where the wires are strung to a fairly even tension, and the hangers of the proper length, and all parts securely and tightly drawn up, there would not be any tendency to roll when the line is properly adjusted. If one of the wires is much tighter than the other there will, of course, be a tendency for the structure to get out of position.

I agree with Mr. Thurston that it is very desirable to have the connection at the top of the spacing rod flexible, so as to allow it to move with reference to the messenger wire. This is an instance of the value of practical experience—in showing the value of flexibility, which engineers were chary of a few years ago.

Mr. Harte emphasized the interesting fact that successful operation depends on uniformity of resistance at the contact surface, *i.e.*, hard spots should be kept out of a yielding line or soft spots out of a hard line, or, in other words, the line should be either uniformly hard or uniformly yielding. The successful operation of the Denver & Interurban catenary line has been due to the fact that it was uniformly hard and smooth, and the reason why it was built in that manner was, in the first place, because it was necessary to use the sliding pantograph bow, the wheel trolley being regarded as impracticable; secondly, we had to make use of such types of hangers as were commercially available at the time, there being no flexible type hangers of known reliability then manufactured; consequently it was impossible to construct a line which we could be sure would be uniformly flexible, and we were therefore obliged to adopt the method of making the line uniformly hard and smooth, which was done in the manner indicated in the paper, and which has proved to be successful as a working proposition. Having no means for making the line flexible, we did the next best thing; and while I will readily admit that it would in some respects have been an easier line to build if it had not been necessary to draw it so tight, two years of operation and maintenance have developed no defects, and apparently it is as satisfactory to operate as though it were of the flexible type.

The experimental lines constructed with flexible hangers mentioned by Mr. Hixon and Mr. Harte will doubtless have considerable effect in determining the development of catenary details, but it now appears that both the Schenectady and Connecticut lines are operating with wheel trolleys and not with sliding bows. It seems to me that the contact-making conditions which must be ultimately fulfilled by equipment

for heavy traction are not being met in these installations, and to that extent they will be somewhat inconclusive. It they should be tried out with pantagraph trolleys of the sliding or roller type, then there would be something definite upon which to base conclusions for the heavy and high speed work of the future.

The question of clearance referred to by Mr. Kempton, is, of course, one that pertains to conditions on each particular job; 8 feet was mentioned as a minimum which was actually used in a large installation without any bad results. I believe, however, that 8½ feet is better, as used on the Denver & Interurban line.

The inclination of the trolley brackets on curves was varied from the horizontal; if car leaned away from the pole, the bracket is inclined downwards; if toward the pole, the bracket is inclined upwards, in order to prevent the horizontal pantograph bar from fouling the bracket arm.

The roller type of trolley contact has been in use in Europe for some years; the Valtellina installation in Italy being perhaps the best known instance of its application there. I referred to its use on the Pacific coast as the first and only application of its use in this country. Since writing the paper I have ascertained through the *Electric Journal* that on the Valtellina line, where the overhead construction is not very tight (and not of the catenary type) the rollers have an average life of 15,500 miles and frequently carry more than 200 amperes per roller, and that in the opinion of Mr. Von Kando of the Italian Westinghouse Co. the excellent life of the contact roller is due partly to the difference between rolling and sliding friction, and partly to the fact that each element of the roller is heated by the passing current only at the instant of contact, and does not remain in contact long enough to get melted; while with the sliding contact the wear is excessive when the current is more than 50 amperes.

It seems to be agreed that the vertical flexible working conductor is very desirable, and the best reports of smooth operation with it emanate from installations where the rolling and not the sliding contact is used.

It is my belief that trolley pole and wheel are not suitable for heavy railroad operation at high tensions and speeds, and that the horizontal transverse form of contact device is indispensable under such conditions; and I suggest that the next step forward should be in the development of the roller type of contact against the yielding or floating trolley wire, in which the elements of wire tension, contact pressure, and pantograph inertia will be compromised to produce the desired effect.

It has been stated by men who have had good opportunities for actual observation, that when speeds of 45 miles per hour or so are exceeded, the conditions to be met by an overhead contact device for heavy currents are so difficult as to be beyond the

field of experience at lower speeds. Granting this to be true, there is all the more reason for developing practical mechanical devices for making contact. Only experiment can decide the question positively, and it remains to be seen whether the devices above suggested can be adapted to high speed, or whether recourse must be had to some combination yet to be invented.

Edwin B. Katte (by letter): The following is a description of porcelain strain insulators used upon a recently constructed 11,000-volt aerial transmission line and a 650-volt direct current distribution system.

Specifications. The 11,000-volt strain insulators shall be of two piece construction; the 650-volt strain insulators shall be a single piece of porcelain. Porcelain surfaces shall be thoroughly glazed a uniform brown color, shall be free from pits, cracks or other imperfections and the material sound and homogeneous throughout. All insulators shall conform to the dimensions

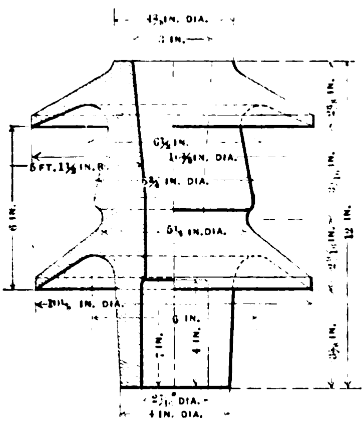


Fig. 1.—High-tension insulator

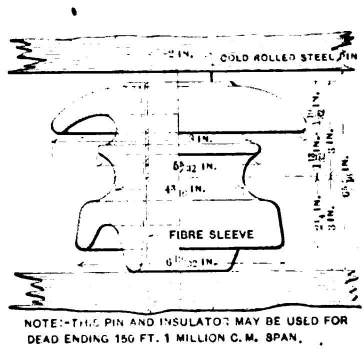


Fig. 2— Low-tension insulator

given on the attached illustration, Fig. 1 and Fig. 2, within 3/32 in. except those given for pin holes which shall conform to the drawing to within 1/16 in.

Tests. The contractor shall supply for test free of cost 2 per cent of the insulators from each furnace charge. These shall be broken and on the exposed surface shall be placed drops of red ink which shall not spread or show signs of absorption. The exposed surface shall be free from cracks, checks, blow-holes, etc., and shall show a close and uniform grain.

A. *High Tension Strain Insulators.* Each 11,000-volt strain insulator selected by the inspector shall be mounted on a two-in. metal pin, shall be subjected to a potential of 80,000 volts applied between the pin and the wire groove for one minute without showing signs of breakdown, leakage or excessive brush discharges. When mounted in a vertical position on a 2-in. metal pin and

subjected to a precipitation of ⅜ in. of clear water per minute with current applied between pin and wire groove the insulators shall not break down or arc over at less than 50,000 volts. Each insulator when mounted upon a steel bar in a manner to be approved by the engineer shall safely withstand a continuous load perpendicular to the pin of 9,000 lb. applied by means of a No. 4/0 seven-strand, hard-drawn copper cable.

B. *Low Tension Strain Insulators.* Each 650-volt strain insulator selected by the inspector shall be mounted on a 2-inch metal pin, shall be subjected to a potential of 30,000 volts applied between the pin and the wire groove for one minute without showing indications of conductivity, breakdown or surface leakage. When mounted in a vertical position on a 2-inch metal pin and subjected to a precipitation of ⅜ of an inch of clear water per minute with current applied between pin and wire groove the insulator shall not break down or arc over at less than 16,000 volts. Each insulator when mounted upon a steel bar in a manner to be approved by the engineer shall safely withstand a continuous load perpendicular to the pin of 10,000 lb. applied by means of a 1,000,000 circular mill, 91-strand, hard-drawn copper cable. Each insulator shall withstand, momentarily, without sign of fracture, 15,000 lb. applied in the manner specified.

SUMMARY OF TESTS

Type of insulator	Electrical requirements
11,000-volt strain	Dry, 80,000 volts for one minute.
	Wet, 50,000 volts without arcing.
650-volt strain	Dry, 30,000 volts for one minute.
	Wet, 16,000 volts without arcing.
	Mechanical requirements
11,000-volt strain	Continuous load of 9,000 lb.
650-volt strain	Continuous load of 10,000 lb.
650-volt strain	Momentarily load of 15,000 lb.

Inspection Results. Competitive bids were invited for high and low tension strain insulators and the contract finally awarded to an insulator manufacturer of high standing. Insulators were offered for inspection and acceptance with the following results:

Type of insulator	Total No. delivered	Number accepted	Per cent rejected
11,000-volt strain	156	129	17.3
650-volt strain	172	163	5.2

Mechanical Tests. From a large number of tests to determine the mechanical strength of the insulators the following have been selected as typical:

11,000 VOLT STRAIN INSULATORS

No. of test	Pounds pressure	Time pressure applied	Remarks
13	11,390	5 mins.	O. K.
13	13,400	3 mins.	Cracks developed.
13	13,735	Instantly	Failure.
14	8040	10 mins.	O. K.
14	10 720	2 mins.	Cracks developed.
14	11,055	Instantly.	Failure.

650 VOLT STRAIN INSULATORS

11	6,700	5 mins.	O. K.
11	10,050	3 mins.	O. K.
11	10,385	Instantly	Failure.
12	8,710	3 mins.	O. K.
12	12,060	2 mins.	O. K.
12	13,400	Instantly.	Failure.

Results in Service. The insulators described above have been in continuous service for about three years with the following results.

Type of insulator	No. installed	Mech. failures	Elec. failures	Broken by violence	Per cent Failure from all causes
High tension strain............	101	5	0	0	4.9
Low tension strain.............	86	8	0	0	9.4

Conclusions. It must be concluded from the above that the per cent of mechanical failures has been high considering the care with which the original shipments were inspected and tested. For the relatively low voltages there is no difficulty in securing the requisite electrical strength, but further combined efforts of engineers and manufacturers are necessary to secure greater mechanical strength in porcelain strain insulators for heavy service.

REPORT OF THE LIBRARY COMMITTEE

For Year Ending April 30, 1910

We submit herewith our report giving the more important features of the growth and operation of the Library for the year ending April 30, 1910, together with a statement of the present condition of the several funds and expenditures for the year.

The gifts to the Library through its members and others have reached a total of 975 volumes and pamphlets. 287 volumes have been added through purchase and 54 volumes have been received through exchange for the PROCEEDINGS of the Institute. The total additions are therefore 1320 titles.

In the table of statistics given below a large number of pamphlets have been added which were received in the previous year but which have not been listed or accessioned at the time of the last report.

The total valuation is shown in the table below and a complete list of donors with the number of volumes or pamphlets presented by each is as follows:

DONORS

ADAMS, S. C	3
AERONAUTIC SOCIETY OF NEW YORK	1
ALLEGEMEINE ELEKTRICITATS GESELLSCHRAFT	3
ALMANNA SVENSKA ELEKTRISKA AKTIEBOLAGET	1
ALUMINIUM COMPANY OF AMERICA	5
AMERICAN CIVIC ASSOCIATION	1
AMERICAN INSTITUTE OF ARCHITECTS	2
AMERICAN MINING CONGRESS	3
AMERICAN RAILWAY ASSOCIATION	7
AMERICAN SOCIETY OF AGRICULTURAL ENGINEERS	1
AMERICAN SOCIETY OF ENGINEERING CONTRACTORS	1
AMERICAN STREET AND INTERURBAN RAILWAY ASSOCIATION	6
ARMSTRONG CORK COMPANY	1
ARNOLD, B. J	1
ASSOCIATION OF LICENSED AUTOMOBILE ENGINEERS	1
ASSOCIATION OF VERMONT ENGINEERS	1
BAEYER, O. V	1
BAKER ELECTRIC COMPANY	2
BENTLEY, E. M	1
BOSTON SOCIETY FOR CIVIL ENGINEERS	1
BOSTON TRANSIT COMMISSION	1
BROOKLYN ENGINEERS CLUB	1
BURCH, E. P	1
BUREAU OF LONGITUDE, PARIS	1
CALDWELL, EDWARD	22
CAMBRIDGE (MASS.) BRIDGE COMMISSIONERS	1

CANADIAN ELECTRICAL ASSOCIATION	1
CANADIAN ENGINEER	1
CARNEGIE INSTITUTE OF WASHINGTON	4
CARNEGIE LIBRARY OF PITTSBURGH	1
CIVIC LEAGUE OF SAN FRANCISCO	3
CLARK, MYRON C. PUBLISHING COMPANY	1
CLAYTON, W. B. AND CRAIG, J. W	1
CLEVELAND ENGINEERING SOCIETY	1
COHRANE PUBLISHING COMPANY	1
COLUMBIA UNIVERSITY	9
COMISION 4 CONGRESO CIENTIFICO (CHILE)	3
CONNECTICUT BUREAU OF LABOR	1
CUSHING, H. C., JR	1
ELECTRIC TRADES ASSOCIATION OF THE PACIFIC COAST	1
ELECTROCHEMICAL & METALLURGICAL INDUSTRY	1
ENGINEERS CLUB OF CENTRAL PENNSYLVANIA	1
ENGINEERS CLUB OF PHILADELPHIA	1
ENGINEERS CLUB OF ST. LOUIS	1
ENGINEERS CLUB OF TORONTO	1
ENGINEERING STANDARDS COMMITTEE	1
FIDELITY & CASUALTY COMPANY OF NEW YORK	1
GENERAL ELECTRIC COMPANY (INCOMPLETE)	3
GESELLSCHAFT FUR DRAHTLOSE TELEGRAPHIE, BERLIN	1
GILBRETH, F.B	1
GUYE, P. A	1
HEDENBERG, MR	1
HOPELI, U	3
HUELS, F. W	1
HUNTINGTON, MR	1
L'INDUSTRIE DES TRAMWAYS ET CHEMINS DE FER	1
INSURANCE SOCIETY OF NEW YORK	2
INTERNATIONAL AMERICAN SCIENTIFIC CONGRESS	1
ISOLATED PLANT COMPANY	1
JENKS, W. J	4
KANSAS GAS, WATER, ELECTRIC LIGHT & STREET RAILWAY ASSOCIATION	1
KANSAS UNIVERSITY & ENGINEERING EXPERIMENT STATION	1
KENNELLY, A. E	5
KING, MOSES	1
LEWIS INSTITUTE	1
MCMILLAN COMPANY	3
MAILLOUX, C. O	1
MARTIN, JOHN	1
MARTIN, T. C	10
MASSACHUSETTS GAS & ELECTRIC LIGHT COMMISSIONERS	1
MASSACHUSETTS INSTITUTE OF TECHNOLOGY	1
MCGRAW-HILL BOOK COMPANY	117
MICHIGAN ELECTRIC ASSOCIATION	1
MONTANA STATE COLLEGE OF AGRICULTURE & MECHANICS ARTS	1
MUNICIPAL SCHOOL OF TECHNOLOGY MANCHESTER	2

MUNICIPAL ENGINEERS IN THE CITY OF NEW YORK	2
NATIONAL ASSOCIATION OF CEMENT USERS	1
NAIONAL ASSOCIATION OF COTTON MANUFACTURERS	1
NATTIONAL FIRE PROTECTION ASSOCIATION, BOSTON	1
NATIONAL SOCIETY FOR THE PROMOTION OF INDUSTRIAL EDUCATION	2
NEW ORLEANS SEWERAGE & WATER BOARD	1
NEW YORK CITY BOARD OF MAGISTRATES	1
NEW YORK PUBLIC SERVICE COMMISSION, 2ND DISTRICT	22
NEW YORK PUBLIC SERVICE COMMISSION, 1ST DISTRICT	15
NEW YORK STATE EDUCATIONAL DEPARTMENT	2
NEW YORK STATE LABOR DEPARTMENT	1
NEW YORK STATE WATER SUPPLY COMMISSION	1
NEW YORK ELECTRICAL SOCIETY	1
NEW YORK UNIVERSITY	1
OHIO INDEPENDENT TELEPHONE ASSOCIATION	3
PFUND, RICHARD	3
PERU MINISTERO DE FOMENTO	1
PHYSIKALISCH TECHNISCHEN REISHSANSTALT	13
PITTSBURG CHAMBER OF COMMERCE	1
POTAMIAN BRO	1
ROBSON & ADEE	1
ROCHESTER ENGINEERING SOCIETY	1
SHELDON, SAMUEL	1
SIEBEL, F. P	1
SOCIETE INDUSTRIELLE DE L'EST NANCY	1
SOCIETY OF NAVAL ARCHITECTS & MARINE ENGINEERS	11
SPON & CHAMBERLAIN	4
SPRINGER, J	1
STONE & WEBSTER	1
SUBMARINE SIGNAL COMPANY	9
SYDNEY UNIVERSITY ENGINEERING SOCIETY	1
TELEFUNKEN WIRELESS TELEGRAPH COMPANY	27
TELEGRAPHIC HISTORIAL SOCIETY OF NORTH AMERICA	2
THOMPSON, S	1
TRAUTWINE J. C., JR. & J. C. 3RD	2
U. S. CENSUS BUREAU	2
U. S. COAST & GEODETIC SURVEY	8
U. S. GEOLOGICAL SURVEY	8
U. S. INTERSTATE COMMERCE COMMISSION	1
U. S. LIBRARY OF CONGRESS	4
U. S. NAVY DEPARTMENT	2
U. S. STEAM ENGINEERING BUREAU	1
U. S. WAR DEPARTMENT	1
UNIVERSITY OF ILLINOIS—ENGINEERING EXPERIMENTAL STATION (12 NOS. 1 VOL.)	12
UNIVERSITY OF OKLAHOMA	2
UTAH UNIVERSITY OF ENGINEERS	1
VAIL, T. N	1
VAN NOSTRAND D. & COMPANY	8

VILLARS, GAUTHIER	1	
WEAVER, W. D	2	
WENTWORTH, MR	1	
WESTERN ELECTRIC COMPANY	482	
WESTERN UNION TELEGRAPH COMPANY	1	
WESTINGHOUSE ELECTRIC & MANUFACTURING COMPANY	2	
WILEY, JOHN & SONS	1	
WIRELESS INSTITUTE OF NEW YORK	1	
WISCONSIN RAILROAD COMMISSION	1	
WORCESTER POLYTECHNIC INSTITUTE	1	
WYNKOOP, H. S	1	
DONORS UNKNOWN	30	
		979

Other Accessions:

Purchases	287	
Exchanges	54	341
Total Accessions		1320

In the report of one year ago there was outlined a new arrangement under which the library staff had been working. This same arrangement has continued this year with the same staff of employees.

The following tabulation gives the state of the five funds from which the Library committee is entitled to draw.

DONATIONS (GENERAL LIBRARY FUND)

Dr.		Cr.	
Balance May 1, 1909	$251.51		
Interest May 1, 1910	6.53	Unexpended	$258.04
	$258.04		$258.04

MAILLOUX ENDOWMENT FUND ($1,000)

(Proceeds for the maintenance of certain sets of periodical publications.

Balance May 1, 1910	$30.35		
Interest May 1, 1910	$30.00	Unexpended	$60.35
	$60.35		$60.35

INTERNATIONAL ELECTRICAL CONGRESS OF ST. LOUIS, 1904 FUND

Invested in New York City 4½% Bonds			$2268
Additions to the fund			25
Total fund			$2293.80
Balance on hand May 1, 1909	$24.72	Expended	$85.60
Interest to May 1, 1910	90.00	Unexpended	129.12
	214.72		214.72

WEAVER FUND.

Balance on hand May 1, 1909	$65.44	Unexpended	$65.44
	$65.44		$65.44

INSTITUTE APPROPRIATION ACCOUNT.

Dr.		Cr.	
Appropriation for the year ending October 1, 1910	$3,500.00	Librarian and assistants	$1,569.69
		Cataloguing	255.02
		Desk attendant	138.67
		Insurance	80.33
		Binding	377.25
		Books	301.50
		Subscriptions	258.75
		Furniture and Fixtures	167.72
		Miscellaneous	116.80
			$3,265.73
		Unexpended	234.27
	$3,500.00		$3,500.00

The general statistics of the Library and its valuation are shown in the following tabulation:

STATISTICS OF LIBRARY, MAY 1, 1910

Source	Volumes	Pam-phlets	Valuations
Report of May 1, 1909	13,515	565	$24,566.23
Purchases	287		522.94
Gifts and exchanges	1063		769.95
Old material accessioned		714	100.00
	14865	1279	$25,959.12

In the following table are given the figures for the total valuation of the library property:

Books	$25,959.12
Stacks	1,761.05
Furniture, Catalogues, cases, etc	376.00
	$28,096.17

LIBRARY ATTENDANCE

	Day	Night	Total
May 1909	462	221	683
June "	484	198	682
July "	472	Closed	472
August "	472	Closed	472
September "	434	220	654
October "	471	238	709
November "	479	223	702
December "	545	301	846
January 1910	460	286	746
February "	416	232	648
March "	439	256	695
April "	488	272	760
Total May 1909–April 1910	5622	2447	8069

New Indexing

The very valuable set of telephone litigation records presented to the library a few years ago, comprising about 100 volumes have been thoroughly catalogued during the year. The total number of card entries required for this set was about 1300 and these are now incorporated in the general card catalogue of the library.

The general catalogue has also been increased by the addition of cards bearing all of the entries in the two-volume bibliography of the Wheeler collection published last year.

The splendid gift of the Western Electric Company deserves special mention. This consists of 482 volumes of United States Patent Office Certified Specifications, including a copy of every specification from May 30, 1871 to March 1896 and of every electrical specification from July 1887 to December 1907. The set makes a splendid foundation for a patent library. During the year the volumes of certified specifications from April 1896 to December 1906 were purchased, making the set now in the library complete from the beginning of the certified series to the end of 1906, and it is expected this will soon be brought up to date.

Another gift worthy of special mention is the Diary of Samuel F. B. Morse presented by Mr. Thomas A. Edison. This diary is 13 inches in length by 8 inches in width, a formal book of white ruled paper bound in stiff boards. The book contains some 45 pages of copies of official correspondence with the United States Treasury by Morse as Superintendent of Electromagnetic Telegraphs, followed by about 8 pages of personal notes. The dates range through 1843 and 1844 while some of the later entries are made in 1848. A full and sympathetic description by Mr. T. C. Martin of this interesting book with fac similes of some of its entries is printed in the Metropolitan Magazine for April 1910, under the appropriate title " From One Genius to Another: a forgotten diary of S. B. Morse and how it was found by Thomas A. Edison."

Mr. Edward D. Adams has continued his contributions to the library as in previous years by the donation of the Proceedings and Transactions of the Royal Society of London, and new volumes of the International Catalogue of Scientific Literature. He has also as heretofore had these volumes bound at his expense.

The " C. O. Mailloux Fund " of $1000 has again been used to maintain the four important periodical sets which were originally presented to the library by Mr. Mailloux.

LIBRARY COMMITTEE
W. G. Carlton.
Charles L. Clarke.
H. E. Clifford.
Philip Torchio.
Edw. Caldwell.
Chairman.

July 28, 1910.

A paper presented at the 252d meeting of the American Institute of Electrical Engineers New York, October 14, 1910.

POTENTIAL STRESSES IN DIELECTRICS

BY HAROLD S. OSBORNE AND HAROLD PENDER.

HIGH VOLTAGE INSULATION

The property of a dielectric in which one is particularly interested in the design of high voltage insulation is its ability to resist the stresses exerted upon it by the voltage, tending to disrupt it, and to force a large current through the puncture.

The fundamental assumption which is made with regard to this property is that the force tending to disrupt the material at any point is measured by the electric intensity at that point, that is, by the force which would act upon a unit charge placed at that point. Thus Maxwell makes this statement:[1]

"If the electromotive intensity at any point in a dielectric is gradually increased, a limit is at length reached at which there is a sudden electrical discharge through the dielectric. The electromotive intensity when this takes place is a measure of what we may call the electric strength of the dielectric."

This critical value of the electric intensity in a dielectric is itself called, in common parlance, the electric strength of the dielectric.

Granting the existence of this definite physical constant, the electric strength of a dielectric, that is, a definite value of electric intensity which cannot be continuously or repeatedly exceeded without disrupting the dielectric, the voltage required to break down a given design of insulation depends evidently upon two factors:

1. The electric strength of the dielectric.
2. The distribution of the electric intensity, or, as one may now call it, the electric stress, in the dielectric.

1. *Electricity and Magnetism*, Vol. I, Art. 55.

With regard to the electric strength of the dielectric it need only be remarked that if one could devise materials of any desired electric strength and the necessary mechanical properties, insulation problems would be at an end. There seems little prospect, however, of the production of materials having greatly increased electric strengths until our knowledge of the constitution of matter is much more intimate than it is at present.

The second factor, the distribution of electric stress in the dielectric, depends upon its configuration. With an ideal distribution, the stress would be uniform throughout the dielectric, but in a homogeneous material this distribution can unfortunately occur only between infinite parallel conducting planes, which are not to be found in practice. When a conductor is insulated by surrounding it with a homogeneous dielectric, the stress is greatest at the surface of the conductor and less on the outside layers of insulation. Because of this non-uniformity in the distribution of the stress, the breakdown voltage of the wall of insulation is less than the product of its electric strength and its thickness. In high voltage insulation, the thickness of the wall required is relatively great, and the non-uniformity in the distribution of stress is so great that it becomes important to increase, by some device, the stress on the outer layers of insulation, so that they may be stressed equally with the inner layers.

In considering methods of accomplishing this result, those methods applicable to apparatus for alternating-current working are of primary importance. If one imagines the insulation to be divided into layers, it may then be considered as a set of capacities in series, the inner capacities being the smaller and hence supporting the greater stress. Two general methods are used in equalizing the stress on the layers. This equalization is accomplished either:

1. By connecting layers of metal foil, separating the layers of insulation, to points of suitable potential.
2. By increasing the capacity of the inner layers.

These same methods may be applied to apparatus for direct-current working, if it be borne in mind, in applying the second method, that in direct-current working the eventual stresses on the different layers are determined by their relative conductances instead of by their relative capacities.

The first method, requiring sources of various potentials, is not adapted to many cases, but can be conveniently applied in the insulation of a transformer, where any desired voltage

may be tapped from the high tension winding. In England a patent[2] has been granted to the Siemen's Bros. Dynamo Works, Ltd., covering this method of insulating high voltage transformers. Much the same expedient has been suggested[3] by Professor H. J. Ryan for protecting against excessive stresses the minor insulation of high-voltage windings.

The most obvious way of applying the second method of equalizing the stress, that of increasing the capacity of the inner layers, is to separate the layers by metal foil, and connect additional condensers across the inner layers. This method has been suggested for underground cables, but it has the disadvantage that it requires apparatus external to the cables themselves. This method has, however, been applied very ingeniously and successfully to the design of the condenser type of transformer terminal, which has been recently described[4] by Mr. A. B. Reynders in a paper presented to the American Institute of Electrical Engineers.

A method of increasing the capacity of the inner layers which is capable of a broader application, and which does not require the insertion of metallic layers, is the *grading* of the specific capacity (also called the dielectric constant) of the dielectric, making it higher in the inner layers than in the outer. This method has the advantage that it does not require the insertion of metallic layers between the layers of insulation. It is this method which is being applied in the manufacture of extra-high tension cables.

The Grading of Cables

The grading of cables seems to be worthy of a detailed consideration for three reasons:

1. The single-conductor concentric cable is of simple enough configuration to permit of mathematical treatment with the ordinary methods of analysis, so that a complete theoretical solution can be worked out of the problem of so grading the cable as to give a maximum voltage strength.

2. The manufacture of high voltage cables is now of commercial importance, and its seems certain that the demand for graded cables will increase with further development of high-voltage underground transmission.

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2. British Patent 21869 of 1907. Engineering, July 17, 1908.

3. *Some Elements in the Design of High Pressure Insulation.* International Electrical Congress of St. Louis, 1904.

4. PROCEEDINGS of the American Institute of Electrical Engineers, March, 1909.

3. It is worth while for engineers, who frequently specify the thickness of insulation on their cables, to understand the possibilities offered by grading. In a rubber-insulated cable which was recently manufactured, the thickness of insulation specified by the purchasing engineer was so great that the manufacturer found it expedient to put the rubber on in two layers, though these layers were ungraded. If those layers had been properly graded, the cable could have been built with one-fourth the volume of insulation actually specified, and operated with the same maximum stresses.

Historical. The grading of cables has been discussed in several papers, the more notable of which are mentioned below.

It seems to have been first pointed out[5] to engineers by Mr. J. Swinburne, in 1897, that the electric stress in concentric cables is not uniform, but varies inversely as the distance from the axis of the cable. Mr. M. O'Gorman, in 1901, suggested[6] remedying this defect by *grading* the electrical constants of the wrappings, so that the outer layers should be stressed equally with the inner. In particular, he proposed to increase the conductivity of the inner layers of direct-current, impregnated paper cables by adding small portions of linseed oil, or of a similar oil, to the impregnating compound.

Mr. E. Jona, of Pirelli & Co., Milan, discussed the grading of cables in a classical paper[7] presented to the International Electrical Congress in 1904. Among other things, this paper describes a graded rubber-paper cable which was built by Pirelli & Co., gives the results of a theoretical investigation of the effect on the stress of stranding the conductor, and recounts some experiments made by Mr. Jona, to which frequent reference is made later in this paper.

Still more recently, Professor A. Russell has presented[8] this subject to the Institution of Electrical Engineers. Professor Russell's paper discusses methods of determining the electric strength of materials, and a number of interesting questions, such as the effect of temperature and of conductance on the distribution of the stress. In this paper are also presented

5. In a paper on *Electrical Transformation* before the Eng. Society. See Mr. O'Gorman's paper, Note (6).

6. Journal of the Institution of Electrical Engineers, Vol. 30, p. 608. 1901.

7. Transactions of the International Electrical Congress of St. Louis, 1904. Vol. II, p. 550.

8. Journal of the Institution of Electrical Engineers. Vol. 40, p. 6. 1908.

formulæ for grading concentric cables, derived on the assumption that all the layers of insulation should be subjected to the same maximum and minimum stresses.

Grading Formulæ. For heavy walls of insulation Professor Russell's formulæ do not give the best possible designs. The problem of determining the constants of a graded single-conductor cable of a given type in such proportions as to give the maximum possible voltage strength can be solved in the manner indicated below.

The electric intensity near a long, uniformly charged wire which is surrounded by concentric layers of insulation is found by a simple integration, to be equal to

$$F = \frac{2\,Q}{\varepsilon\,\rho} \qquad (1)$$

where Q is the charge on the wire per unit length, ε is the specific capacity of the dielectric at the point considered, and ρ is the distance of that point from the axis of the wire.

If the conductor has a radius of r_0, and is surrounded by a homogeneous insulation of outer radius r_n, and by a conducting sheath, the expression for the electric stress becomes

$$F = \frac{V_0}{\rho \ln \frac{r_n}{r_0}} \qquad (2)$$

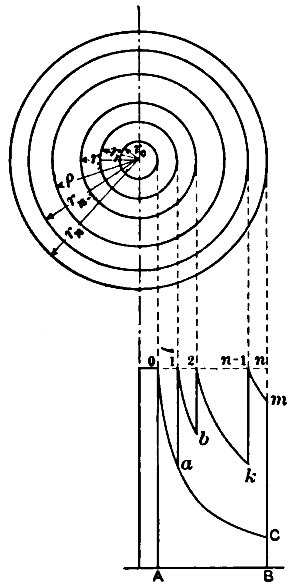

Fig. 1.—Potential gradient in a single-conductor cable

where V_0 is the potential difference between the conductor and the sheath.

The distribution of stress is then represented by the curve $O\,a\,C$, Fig. 1, and if $O\,A$ represents the electric strength of the dielectric, the area $A\;O\;a\;C\;B$ represents the highest voltage which can be impressed upon the conductor without rupturing a part, at least, of the wall of insulation. If the stress were uniform throughout the wall of insulation, the rupturing voltage would be represented by the rectangle $A\;O\;n\;B$.

If now the insulation be divided into layers having outer radii of r_1, r_2, etc., and specific capacities of ε_1, ε_2, etc., respectively

so graded that the stress at the inside of each layer is brought up to the value $A\,O$, or to the electric strength of the material; the rupturing voltage of the cable is evidently represented by the area $O\,a\,1\,b\,2\,.\,.\,.\,.\,.\,k\,(n-1)\,m\,B\,A$, and approaches nearer and nearer to the maximum value, rectangle $A\,o\,n\,B$, the greater the number of layers.

In such a graded cable the equation for the stress becomes

$$F = \frac{1}{\varepsilon\,\rho} \cdot \frac{V_0}{\frac{1}{\varepsilon_1} ln \frac{r_1}{r_0} + \frac{1}{\varepsilon_2} ln \frac{r_2}{r_1} + \ldots + \frac{1}{\varepsilon_n} ln \frac{r_n}{r_{n-1}}} \qquad (3)$$

Since the maximum stress on each layer is at its inner radius, the voltage which will just cause breakdown of the inner layer is

$$V_0 = F_1\,\varepsilon_1\,r_0 \left[\sum_{1}^{n-1} \frac{1}{\varepsilon_k} ln \frac{r_k}{r_{k-1}} \right] \qquad (4)$$

where F_1 represents the electric strength of the inner layer.

If all the layers are to be stressed to the point of disruption by the same voltage, we must evidently make

$$F_1\,\varepsilon_1\,r_0 = F_2\,\varepsilon_2\,r_1 = \ldots\ldots = F_n\,\varepsilon_n\,r_{n-1}\,. \qquad (5)$$

where F_k is the electric strength of the kth layer.

Under these conditions formula (4) for the disrupting voltage is

$$V_0 = F_1\,\varepsilon_1\,r_0 \left[\sum_{1}^{n-1} \frac{1}{\varepsilon_k} ln \frac{F_k\,\varepsilon_k}{F_{k+1}\,\varepsilon_{k+1}} + \frac{1}{\varepsilon_n} ln \frac{F_n\,\varepsilon_n\,r_n}{F_1\,\varepsilon_1\,r_0} \right] \qquad (6)$$

The problem now becomes that of finding the maximum value of V_0 in equation (6) under any given conditions and under simultaneous variation of all its variable factors. It is evident that V_0 increases indefinitely with r_n, so that quantity cannot be considered variable in obtaining a mathematical maximum. V_0 also increases indefinitely, in general, with the electric strengths. However, since these electric strengths are limited at present, in the manufacture of cables, to a very few values, they are not properly considered variable.

The specific capacities can be varied throughout a certain range, both in impregnated paper and in rubber compounds, without materially affecting the electric strength of the material.

We may then determine a mathematical maximum of V_0 for any of these conditions:

1. The outside diameter, $2\,r_n$, alone fixed. V_0 depends in this case upon the n independent variables $r_0, \frac{\varepsilon_1}{\varepsilon_2}, \frac{\varepsilon_1}{\varepsilon_3}, \ldots \frac{\varepsilon_1}{\varepsilon_n}$ and its maximum value is the maximum voltage which can be insulated by a given external diameter of the given materials.

2. The outside diameter, $2\,r_n$, and the diameter of the conductor, $2\,r_0$, fixed. V_0 is then a function of the $(n-1)$ independent variables $\frac{\varepsilon_1}{\varepsilon_2}, \frac{\varepsilon_1}{\varepsilon_3}, \ldots \frac{\varepsilon_1}{\varepsilon_n}$. The conditions for maximum V_0 give the constants of a cable which will insulate a given conductor for a given voltage with the smallest possible outside diameter of insulation.

3. The extreme radii (r_n and r_0) fixed, and also the extreme ratio of specific capacities, $\frac{\varepsilon_1}{\varepsilon_n}$. This last limitation is imposed in many cases by the present commercial limit in the variability of the specific capacities. V_0 then depends upon the $n-2$ independent variables $\frac{\varepsilon_1}{\varepsilon_2}, \frac{\varepsilon_1}{\varepsilon_3}, \ldots \frac{\varepsilon_1}{\varepsilon_{n-1}}$. The conditions for maximum V_0 give the same results as those for the second case, but under this added restricting condition.

Design Curves. The formulæ[9] expressing these conditions, and the resulting design formulæ for graded cables, are implicit logarithmic equations. From them, however, may be plotted curves from which the best designs may be read directly. Figures 2, 3, 4, and 5 show these design curves for four different types of cable. If one wishes to insulate a given size of conductor for a given voltage, he takes the required ratio of diameter of insulation to diameter of conductor from curve B, that ratio being read from curve A if one wishes to design for a given voltage an insulation with a given outside diameter. With a determined value of $\frac{r_n}{r_0}$ the other quantities of the design are read directly

9. See Appendix, Note 1.

from the curves. The values of the intermediate radii of the layers are obtained by remembering that

$$F_1 \varepsilon_1 r_0 = F_2 \varepsilon_2 r_1 = \ . \ . \ . \ . \ . \ . = F_n \varepsilon_n r_{n-1} \qquad (5)$$

The solid line marked *Max.* gives the value of $\frac{r_n}{r_0}$ for the largest ratio of voltage to outside diameter. The vertical dot-and-dash line cuts the curves at that value of $\frac{r_n}{r_0}$ which calls for a ratio of specific capacities which seems to be the present commercial limit. For larger values of $\frac{r_n}{r_0}$ we must

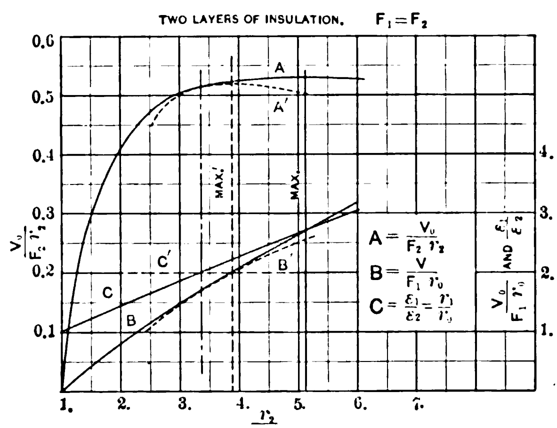

FIG. 2.—Design curves of a single-conductor cable

introduce the condition that the value of $\frac{\varepsilon_1}{\varepsilon_n}$ is kept constant at this maximum value. The design under this added condition is represented by the dotted curves, and *Max'* represents the highest ratio of voltage to outside diameter which can then be obtained.

Figs. 2 and 4 are for cables of two layers and three layers respectively, the layers being all of the same strength. The maximum ratio of specific capacities attainable at present is taken to be two, which seems to be about correct for either rubber or impregnated paper insulations.

Figs. 3 and 5 give the curves for two-layer and three-layer cables respectively, in which the outside layer has an electric strength equal to two-thirds that of the inside layer. This is

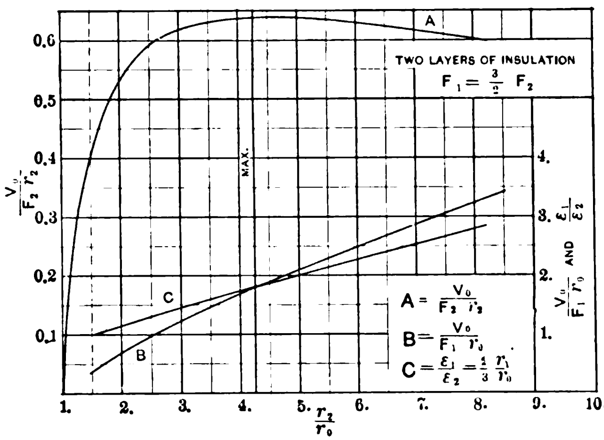

FIG. 3.—Design curves of a single-conductor cable

about the ratio between the electric strengths of impregnated paper and rubber, and these curves may be used for the design of cables having inside layers of rubber and an outside layer of

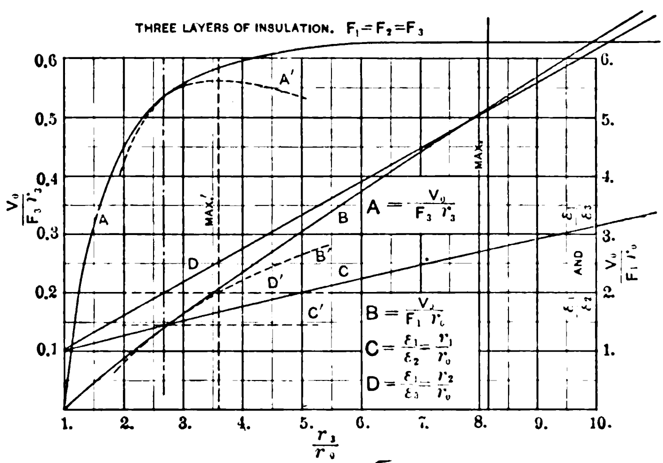

FIG. 4.—Design curves of a single conductor cable

paper. The commercial range of specific capacities for this case seems at present to be about 2.4, and curves have been drawn for this maximum value of $\frac{\varepsilon_1}{\varepsilon_n}$.

It is interesting to note the greatest voltage which can be applied to cables of different designs having a diameter over the insulation of 70 mm. (about the largest that can be drawn, when sheathed, into a standard duct), the allowable stress in the rubber

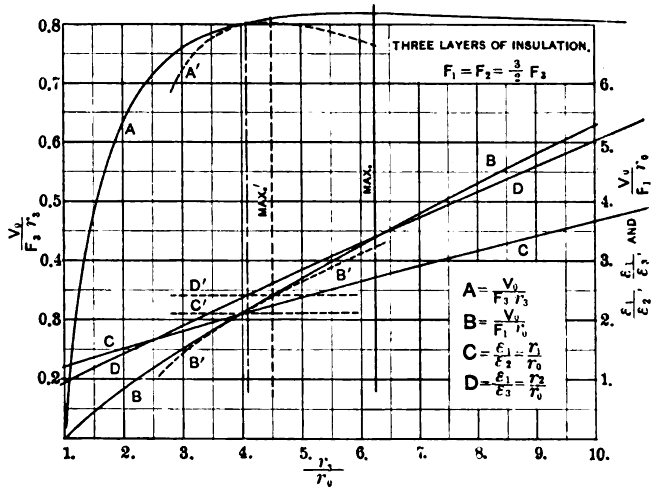

FIG. 5.—Design curves of a single-conductor cable

being assumed to be 6 kv. per mm. (effective), and that on the paper 4 kv. per mm. It is assumed that the available variation in specific capacities is sufficient to allow the best designs. The results obtainable are shown in table I.

TABLE I

No. layers	Insulation	Dia. of core mm.	Circular mils	V_0 (kilovolts)
1	All rubber....................	12.9	1030000	78
2	All rubber....................	6.85	290000	112
3	All rubber....................	4.29	114000	132
2	Rubber-paper................	8.24	420000	90
3	Rubber-rubber-paper..........	5.59	194000	115

Fig. 6 compares what may be called the voltage efficiencies of the different designs, that is to say, the voltage sufficient to overstress a given cable is expressed as a fraction of the voltage which would puncture a uniformly stressed layer of insulation having a thickness equal to the outside radius of the insulation

of the cable. The maxima are indicated by short vertical lines, and it is noticeable that the graded cables not only show maxima which are higher and at greater values of $\frac{r_n}{r_0}$ than that for the ungraded cable, but that the curves are much flatter at the maxima than the curve for an ungraded cable. The circles indicate the points at which the present commercial limits in the ratios of specific capacities are passed. The curves for cables having larger values of $\frac{r_n}{r_0}$, and using the commercial limits of $\frac{\varepsilon_1}{\varepsilon_n}$ are somewhat lower than those in Fig. 6.

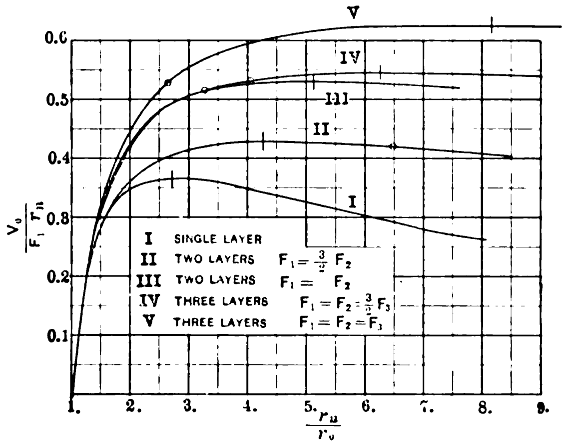

FIG. 6.—Maximum voltage efficiencies of cables

Fig. 7 gives the results of Fig. 6 plotted as percentages of the voltage strength of an ungraded cable. This figure then shows the increase in voltage strength to be gained by grading a cable of given dimensions. Curve I represents in this instance the values for an ideally graded cable, *i.e.*, one having a uniform stress throughout. Curves III and IV so nearly coincide that curve IV has been omitted.

Fig. 8 shows the volume of insulation to be saved by grading a cable of fixed voltage strength and size of conductor. The ordinates are the volumes of insulation required by graded cables expressed in per cents of the volumes required by the ungraded cable. The circles on the curves have the same significance as those in Fig. 6.

Figs. 2 to 8 are sufficient to show the results which can be obtained by the best designs under certain conditions. Formulæ can be derived from the general equations for cables of any desired types. In cases where especial conditions are imposed

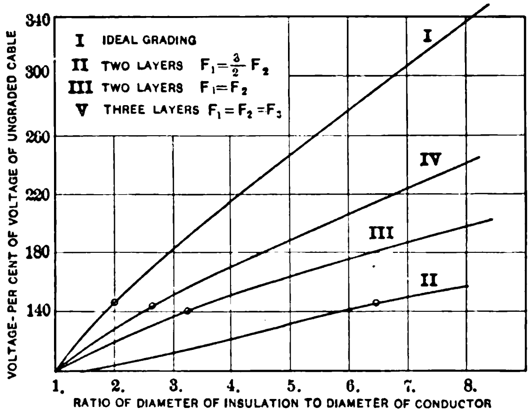

FIG. 7.—Voltage strength of graded cables

by the properties of the materials available or by the conditions of manufacture, the best design can be determined from the general equations.

Conductance of the Dielectric. The results noted above depend

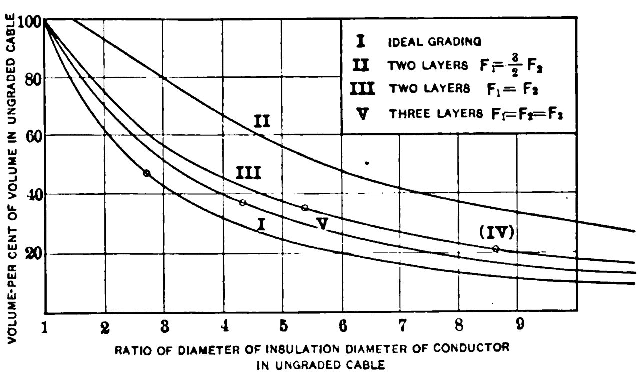

FIG. 8.—Volume of insulation in graded cables

on the assumption that no conductance current flows in the dielectric. This is not true, and it has been pointed out[10] by Professor Russell that the conductance may influence the distribution of stress.

10. See note (8).

If the conductance of the different layers be taken into account equation (**3**) for the stress in the dielectric becomes in complex notation

$$F = \frac{1}{\rho\left[\varepsilon - j\,\dfrac{18\,(10)^{11}\,g}{n}\right]} \cdot \frac{V_0}{\displaystyle\sum_1^n \frac{1}{e_k - j\,\dfrac{18\,(10)^{11}\,g_k}{n}}\, ln\, \frac{r_k}{r_{k-1}}} \qquad (\mathbf{7})$$

where g_k is the conductivity of the kth layer in mhos per cubic cm., and n is the frequency of the impressed sinusoidal electromotive force.

This equation reduces to equation (**3**) under any of the three conditions

$$\left.\begin{array}{l} n = \infty \\ g_1 = g_2 = \ldots\ldots = g_n = 0 \\ \dfrac{g_1}{\varepsilon_1} = \dfrac{g_2}{\varepsilon_2} = \ldots\ldots = \dfrac{g_n}{\varepsilon_n}\,. \end{array}\right\} \qquad (\mathbf{8})$$

In case $n = 0$ (direct-current working), the equation reduces exactly to the form of (3), with the values of ε_1, ε_2, etc., replaced by g_1, g_2, etc., respectively.

From equation (**7**) it may be computed that in any case the effect of conductance is less than five per cent if

$$R\, n\, \varepsilon > 5.6\ (10)^6 \qquad (\mathbf{9})$$

where R is the insulation resistivity in megohms per cubic cm.

This condition, (**9**), is well met by any ordinary frequencies and insulating materials. The complete negligibility of the conductance of the dielectric in ordinary cases is well illustrated by Fig. 9, which shows the effect of low insulation resistance in the inner layer on the charging current of a particular two-layer condenser. It is seen that at commercial frequencies anything having an insulation resistivity of less than 50 megohms acts as a perfect conductor, while any resistivity greater than 40,000 megohms acts as a perfect insulator. The insulation resistivity of impregnated paper is ordinarily stated to be about 10 million megohms, and that of rubber about 800 million megohms.

The effect of conductivity increases with decreasing frequency,

and with continuous pressures the eventual stresses are determined by the relative conductivities of the layers just as they are determined for alternating pressures by the specific capacities.

Temperature. Professor Russell has pointed out that the temperature gradient in the insulation may, by its effect on the conductivity, have a large influence on the distribution of stress in direct-current cables. The effect of the temperature on the specific capacities of ordinary materials is smaller, and in such a direction that it tends to reduce the stress on the inner layers of the insulation.

Multi-Conductor Cables. Cables with two and four, and particularly those with three round conductors inside of a sheath are of such commercial importance that formulæ for grading them are much to be desired. Unfortunately they are like

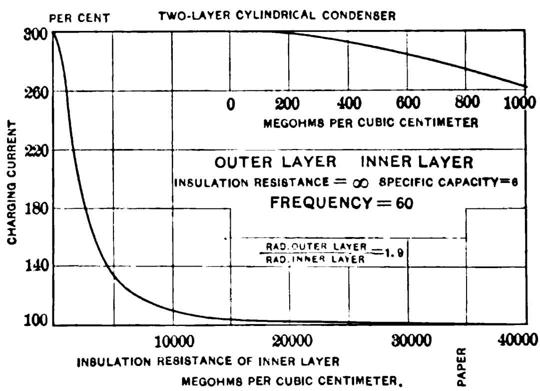

FIG. 9.—Effect of leakage conductance on charging current

almost every other piece of electrical apparatus in that the potential gradient in the insulation cannot be exactly expressed in simple mathematical language.

A familiar approximate solution[11] is obtained by considering the charge on each conductor to be concentrated either at the centre of the conductor or at the appropriate inverse point relative to the sheath. The results obtained by such an approximation are far from exact if the conductors are large relative to the sheath. In cables for very high voltages, however, the conductors must be small relative to the sheath, and in such cases the approximation of such a solution is very good. It seems probable, then, that rational grading formulæ for multi-conductor cables can be developed from the approximate solution.

11. See Appendix, Note 2.

Corona in Solid Dielectrics

The theoretical results which are outlined above rest upon the fundamental assumption concerning electric strength which was noted at the beginning of this paper. It has been assumed that the electric strength of a dielectric is a real physical constant, measured by the electric intensity which, continuously or repeatedly applied, disrupts the dielectric. As this assumption has been assailed, notably in the discussion[12] of Professor Russell's paper, to which reference is made above, it may be worth while to consider it in some detail.

Maxwell laid a foundation for this assumption in the words already quoted: "The electromotive intensity when this (sudden electrical discharge through the dielectric) takes place is a measure of what we may call the electric strength of the dielectric."

Under certain circumstances this disruption extends through only that part of the dielectric which is near the conductors, as is the case in the familiar corona in air, and does not extend through the entire mass of insulation. Reasoning probably from the familiar and undisputed cases of corona, Professor Russell has advanced the hypothesis that there exists in solid dielectrics a corona similar to that in air, which disrupts, the entire overstressed portion uniformly, charring it and rendering it worthless as insulation.

For instance, the insulation about a wire which is insulated to more than 2.7 times its diameter will, according to this hypothesis, as the stress upon it is increased, first break down in a little uniform layer around the conductor. The breakdown of this layer will be insufficient to overstress the rest of the dielectric, so as the voltage is further increased, a zone of uniformly disrupted dielectric will extend out from the wire, within which zone the insulation is valueless, and at the surface of which the stress on the insulation is just equal to its electric strength. After this corona reaches a radius equal to 10/27th of the outside radius of the insulation, any further increase in voltage will overstress the rest of the insulation, and it will puncture.

According to this hypothesis, then, small wires insulated to a large outside diameter with a homogeneous dielectric will all

12. Journal of the Institution of Electrical Engineers, 1908, Vol. 40, p. 33. Professor Russell's paper and this discussion are referred to repeatedly in the following pages.

be expected to puncture, irrespective of the actual size of the wire, at a voltage to be computed by replacing with a conductor all the insulation within 10/27th of the outside diameter of the insulation.

In support of this theory, Professor Russell quoted one of two careful experiments performed by Mr. Jona. He insulated two wires, one of 1 mm. diameter and one of 29 mm. diameter with the same thickness, 14 mm., of paper, and punctured the two cables thus formed. Two similar cables were made with rubber insulation. From the puncturing voltages of the larger cables can be computed the voltages at which the smaller cables should puncture according to Professor Russell's hypothesis. The results observed, and those thus computed, are given in Table II.

TABLE II

Type of insulation	Puncture voltage, computed	Kilovolts observed
Paper	43	40
Rubber	31	22

The agreement in the case of the paper cable is very good. It is interesting to note that in both cases the observed values are even lower than those called for by Professor Russell's hypothesis.

Accepting this hypothesis as correct, one would expect to find a visible change in the layers of insulation which have been subject to corona. Professor Russell quoted several men who have observed the partial destruction of a wall of insulation, but it is not clear in any case that the deterioration observed can be attributed to corona. A visible change in the dielectric is, however, perhaps not a necessary result of the complete destruction of its insulating properties. Professor Russell remarked in closing the discussion of his paper:

"Whether charring occurs or not, I think that once the dielectric has been broken down, it will never prove of much future use, mechanically or electrically, as a covering."

Corona in Air. In absence of experimental proof, it appears that the idea of corona in solid dielectrics has its chief basis on the familiar occurrence of corona in gases. The present state of our knowledge of corona in air is admirably summed up by Mr. E. A. Watson in a paper[13] recently presented to the Institution of Electrical Engineers. Mr. Watson has supplemented the very complete determinations made in this country, notably

13. *Electrician*, London, Feb. 11, 1910.

by Mr. R. D. Mershon,[14] of the corona loss from wires under alternating pressures, by a very valuable series of tests with continuous pressures. His conclusions regarding the character of corona in air may be briefly summarized as follows:

The fact that a loss does occur with direct pressures shows that it is incorrect to consider the alternating current loss to be due to the flow of charging current through the disrupted strata of air, neither can it be considered to be due to the conversion into heat of the electrostatic energy stored in the air when breakdown occurs. Experiments of Rhigi and others have shown that the discharge of electricity from steadily electrified points consists in a stream of gaseous ions moving with a velocity of about 1.5 cm. per second for a field of one volt per cm. Mr. Watson's computations, based on this fact, indicate that the discharge from the wire is carried by certain agglomerations of molecules, and not by the whole mass of air. Tests of the corona in air from different sizes of wire indicate that the electric strength of the air is not constant, but varies inversely with the diameter of the wire, dropping from a value of 81.4 kv. per cm. for a diameter of wire of 0.70 mm., to about 39 kv. per cm. for diameters of 12 mm. or larger. Mr. Watson considers the most reasonable explanation of this to be the assumption that the layers of air next to the wire have a higher electric strength than the main body of air. This is an old idea, suggested by Steinmetz, Ryan and others, and one which seems to have some experimental basis.

These ideas concerning the nature of corona in air, as summed up by Mr. Watson, are of such a nature that it may well be questioned whether there is a similar effect in solid dielectrics. The discussion of Professor Russell's paper before the Institution of Electrical Engineers produced a good deal of opposition to his views on this subject, based largely on the fact that the charring effect of partial breakdown of the dielectric seems not to have been definitely observed. The opinion of a good many men seems to be typified by a remark of Mr. George H. Nisbett in discussing Professor Russell's paper:

"I am further strongly of the opinion that no such effect has been observed as a partial breakdown of a solid dielectric where a layer of air has been entirely absent. I have never seen anything of the sort."

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14. Proceedings of the American Institute of Electrical Engineers, June 1908.

Mr. Jona, whose opinion on this subject is important, remarked in the same discussion:

"I have been engaged for over ten years upon this subject, and my present conclusion is that unfortunately the experiment is most difficult, and often gives results which are not in accord, owing perhaps to the non-homogeniety of the dielectrics, and that theories based solely on the gradient of the potential are deficient. Such theories are partially true, but they do not represent the whole truth."

In support of his views Mr. Jona tells of an experiment with an especial cable. A copper wire 4 mm. in diameter was insulated with jute to 8 mm., surrounded with a thin brass tape, and then with 3 mm. of rubber. With a potential of 8000 volts across this cable, the stress on the jute (3300 volts) was sufficient to puncture it, charging current flowed through to the brass tape, and the entire stress was thrown upon the rubber. This is as one would expect. A second cable was then constructed identical with the first, except that the brass tape was omitted, there being then no conducting layer between the jute and the rubber. On Professor Russell's corona hypothesis one would expect the jute to carbonize at voltages above 8000, and the capacity of the cable to increase eventually to that of the layer of rubber. As a matter of fact no such effect was observed. Mr. Jona found the capacity to be practically constant between 5000 and 15,000 volts. No carbonizing of the jute was observed. This result is distinctly not in accord with the corona hypothesis and may be due, Mr. Jona suggests, to a supporting action of some sort between the jute and the rubber.

Results similar to those of Mr. Jona's experiment have been obtained with a piece of No. 14 wire, insulated to 8.5 times its diameter with rubber. Tests of the electric strength of the rubber with which it is insulated show that at voltages higher than 35,000, the inner part of the rubber is overstressed, and hence, according to the corona hypothesis, the charging current should increase along the curve *A* of Fig. 10. As a matter of fact, it increased along curve *B*. At each point of the curve the voltage was held constant until the capacity stopped increasing. As is indicated by the double points, a slight increase with time was noted; thus at the highest point observed the charging current increased between the two values indicated in two minutes, and then was constant for five minutes. Above 44 kilovolts the cable punctured above the surface of the water in which it

was immersed, at a point where ozone had eaten a deep gash in it. Another piece of the same cable punctured under the water at 50 kilovolts.

Experiments with Cylindrical Condensers. In the attempt to get a more definite indication of the real condition of an overstressed dielectric, a special two-layer cylindrical condenser was constructed. As indicated in Fig. 11 it consisted essentially of a heavy glass tube, or tubes, G, into which was drawn a rubber insulated wire, R. Paraffin terminal pieces, T, were melted onto the ends to prevent end leakage, and to prevent puncturing at the edges of the outer electrode, which consisted of tinfoil wrapped tightly about the tube and about the inner cones of the terminal pieces.

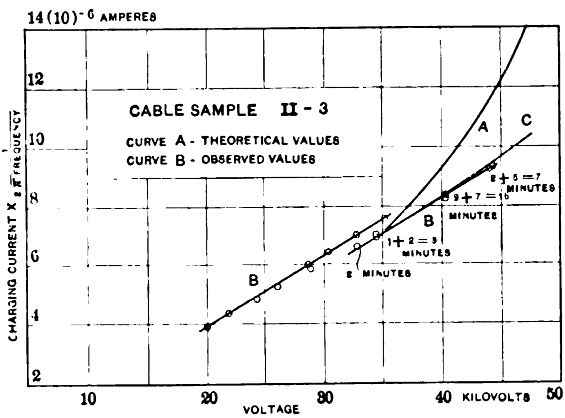


FIG. 10.—Charging Current at high voltages

The method of measuring the charging current is also indicated in Fig. 11. C_0 is a standard condenser, variable between 0.001 and 1 microfarad, connected in a series with the test condenser, E is an electrostatic voltmeter for measuring the voltage drop across C, and P is a protective device. This method was used not only in these experiments, but also in determining the specific capacities of the dielectrics used in the experiments. These constants were thus determined under the conditions ruling during the tests of partial breakdown.

A representative set of constants for the apparatus follows:

Rubber, $\varepsilon_1 = 6.3$ $F_1 = 18.3$

Glass, $\varepsilon_2 = 8.5$ $F_2 = 35+$

The combination therefore forms an inversely graded cylindrical condenser, in which the inner layer is overstressed by voltages which stress the outer layer but slightly.

From the constants of the apparatus it can be computed that at 24 kilovolts the rubber begins to be overstressed, and the charging current should increase, according to the corona hypothesis, along the curve *A* of Fig. 12, assuming, at 27 kilovolts the value due to the capacity of the glass cylinder alone. The curves *B*-1 and *B*-2 represent the values of charging current observed during two successive tests. It is seen that between 24 kilovolts and puncture at 28 kilovolts, the apparent capacity increased but slightly, by no means as much as is called for by the corona hypothesis, that is, by the complete breakdown of the insulation in the overstressed region.

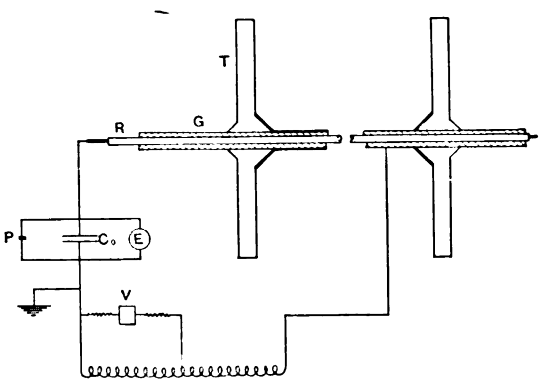


Fig. 11.—Apparatus for measuring charging-current at high voltages

A second, and unexpected, result is that the whole apparatus punctured at 28 kilovolts though the glass tubes alone were capable of withstanding twice that voltage. At this puncturing voltage the potential across the glass tubes, as computed by ordinary methods, was about 10 kilovolts, while that across the rubber was about 16 kilovolts, a little higher than the voltage (13.8 kilovolts) at which the rubber punctures alone.

A third result was obtained by withdrawing the wire from the tubes after the voltage had been applied, and examining it for insulating properties. In appearance, even under the microscope, the rubber was sound. Mechanical tests failed to indicate any deterioration. The insulation resistance of the short lengths used in the test could not be very satisfactorily tested, but it was certainly more than 100 megohms per 1000 meters. When a

voltage test was applied, however, the insulation was found to be markedly deteriorated. Rubber which had been highly overstressed could not withstand at any point a voltage readable on the high-tension apparatus, and rubber which had been but slightly overstressed showed numerous very weak spots.

A difficulty in accepting these results as wholly conclusive arises from the fact that the thin layer of dielectric between the glass and the rubber, where the two did not fit exactly together, was itself disrupted by the voltage stresses. After the first tests had been made with air between the rubber and the glass an unsuccessful search was made for an insulating liquid which would not be overstressed during the experiment. Castor oil

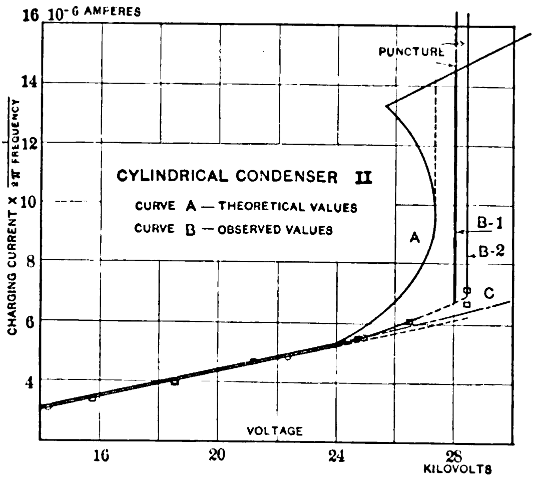


FIG. 12.—Charging current at high voltages

was used in some of the tests, but under the stresses exerted upon it, it evolved little bubbles of gas, even when it had been put under an air-pump directly before the experiment. A test was finally made with a mineral oil which, though it was overstressed during the experiment, showed no bubbles or visible signs of deterioration. The tests with the different insulating liquids all indicate the same results. In the tests the results of which are represented in Fig. 12 castor oil was used between the rubber and the glass.

The possibility remains that if one could introduce between the rubber and the glass an insulating liquid which would not be overstressed during the experiment, the results noted here

would not be observed. Such a possibility seems remote, however, in view of the fact that all the effects observed are explained by a very simple and convincing hypothesis concerning the nature of this partial breakdown.

Let us accept the assumption that an excessive potential gradient at any point always disrupts the dielectric at that point. It seems evident upon consideration that, even in a perfectly homogeneous dielectric, the uniform breakdown required by the Russell hypothesis would be a condition of unstable equilibrium, for if the breakdown proceeds a little farther at one point than at the points around it, the charge flowing into that advanced point will reduce the stress on the surrounding points, and the more intense field at the end of the advanced point will tend to push the breakdown farther and farther into the dielectric. Commercial dielectrics, which cannot be perfectly homogeneous, should then be certainly expected to break down not uniformly, but at a number of points, so that the incipient breakdown produces much the same effect as a number of needlepoints thrust into the insulation.

This simple hypothesis seems to explain all the results of the experiments noted here. When, in the rubber-glass condenser, the needlepoints of disrupted rubber reach the glass, they will tend to puncture it at a much lower voltage than would be required were the inner surface of the glass an equipotential surface. The apparatus punctured in these tests at about 28 kilovolts, though when alone the glass could withstand more than 50 kilovolts. When subjected to potential from an actual steel needlepoint surrounded by insulation, the same tube punctured at about 25 kilovolts. The needlepoints must push their way into the rubber in enough places to keep the stress in the rubber down to its electric strength. They must take some additional charging current, but not nearly as much as would be required were the entire inner layer disrupted, and in a conducting condition. A general idea of the magnitude of this charging current might be obtained by considering that portion of the dielectric which would have become, according to Professor Russell's hypothesis, uniformly disrupted, to support a stress which is uniform and equal to the electric strength of the material. The charging current curves corresponding to this assumption have been drawn in Figures 10 and 12 (Curves *C*). In the test of the cable the curve so computed is in substantial agreement with the observed values. In the experiment with

the rubber-glass condenser the observed values are somewhat greater than those of curve C, partly, perhaps, because some of the needlepoints carried charging current to little bubbles of gas in the castor oil which separated the rubber and the glass.

This idea of the needle-point character of corona in solid dielectrics explains also the results of the experiments quoted by Mr. Jona, making it easy to see how his thick insulations could puncture at voltages even lower than those called for by Professor Russell's hypothesis. It even seems probable that corona in gases is of the same general character, as this idea makes it easier to explain some of the phenomena of that corona. Therefore, though the needlepoint nature of partial breakdown in a dielectric may not be conclusively proved, the substantial accuracy of that idea seems highly probable, because it harmonizes the results of experiment with the fundamental assumption concerning electric stress.

In view of the needlepoint effect, it is particularly desirable to design an insulation for high voltages in such a way that no part of it will be overstressed, for it is apparent from the experiments reported there that an overstressed insulation may be much worse than no insulation at all. It might even pay cable manufacturers who have occasion to make ungraded cables with thick walls of insulation to fill the space within a radius of 10/27th of the outside diameter of their cables, in case it is not wanted for copper, with some material having a conductivity high enough to protect it from excessive voltage gradients, if such a material, having the requisite mechanical properties, is available.

It is desirable to have the results which have been mentioned checked with other apparatus and materials. An attempt was made to do so with a parallel plate condenser, consisting essentially of two glass plates, separated by a weaker dielectric, and separating the two electrodes, one of which was provided with an ample guard ring.

A preliminary test of the apparatus, in which air was the disrupted dielectric, gave the results shown in Fig. 13. The bend in curve I is due to the fact that, owing to irregularities in the glass plates, some air remained between them when they were pressed together. The variations of curve II from the dotted line seem to be largely due to the element of time, and it is not improbable that, were all the other variables eliminated, the voltage across the disrupted air would be found to be sen-

sibly constant, and the current flowing through it largely a displacement current. Mr. A. W. Ewell has conducted an extensive series of tests[15] similar to this, but with plates which were vertical and open to a free supply of air. He found that for large gaps and high voltages, the voltage for a given charging current tended toward a constant value, independent of the width of the air-gap.

A condenser built with paraffin as the weaker dielectric was rejected because of the great contraction of the paraffin on solidifying. A condenser was finally built of a compound[16] which did not contract on solidifying. In testing this condenser the difficulties of insulation were found to be great, and were not surmounted in the short time which remained for the work.

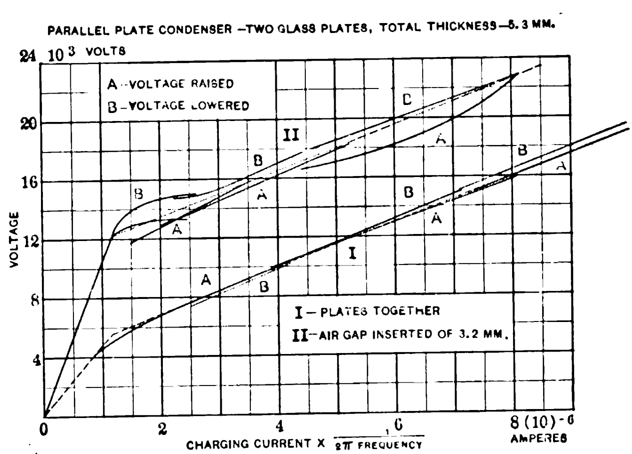


FIG. 13.—Charging current at high voltages

SUMMARY

In the design of high-voltage insulation, resort is made to certain expedients which equalize the stress among the layers of a thick wall of dielectric. In transformers metallic layers, separating the layers of dielectric, can be connected to points of suitable potentials. In the condenser-type of transformer terminal the capacities of the inner layers of insulation are increased by increasing their lengths; and in graded underground

15. *American Journal of Science*, November 1906.

16. The compound consisted in 4 parts of shellac, one part of resin, and 2 parts of venice turpentine. It is recommended by Professor L. T. Moore in an article on *Dielectric Strain along the Lines of Force*, Phil. Mag., December, 1905.

cables the capacities of inner layers is increased by increasing their specific capacities.

Formulæ have been developed which give the best theoretical design of a graded single-conductor cable of certain given types for any given conditions. The effect of the conductivity of the dielectric is found to be entirely negligible for ordinary materials and ordinary frequencies of alternating-current working.

Results of experiment indicate that a solid dielectric, when overstressed, becomes pricked with a number of needlepoints of disrupted material. By this hypothesis these results, and those of earlier experiments, are explained without violating the assumption with regard to the electric strength of a dielectric which is the basis of all analytical work on the subject.

It seems probable, then, that these analytical results are based on proper assumptions; but when they deal with cases of partial breakdown, they must take account of the true character of that breakdown. The experiments reported here were performed in the Electrical Engineering Laboratories of the Massachusetts Institute of Technology. The authors wish to acknowledge their indebtedness to Professor H. E. Clifford for many suggestions concerning the work, and to the Simplex Electrical Company for samples of insulated wire.

Appendix

Note 1. Grading formulæ for concentric cables.

$$V_0 = F_1 \varepsilon_1 r_0 \left[\sum_{1}^{n-1} \frac{1}{\varepsilon_k} \ln \frac{F_k \varepsilon_k}{F_{k+1} \varepsilon_{k+1}} + \frac{1}{\varepsilon_n} \ln \frac{F_n \varepsilon_n r_n}{F_1 \varepsilon_1 r_0} \right] \qquad (6)$$

A. If V_0 is a function of the $n-2$ independent variables $\frac{\varepsilon_1}{\varepsilon_2}, \frac{\varepsilon_1}{\varepsilon_3} \; . \; . \; . \; . \; \frac{\varepsilon_1}{\varepsilon_{n-1}}$, the conditions for a mathematical maximum are

$$\frac{1}{\varepsilon_k} \ln \frac{F_k \varepsilon_k}{F_{k+1} \varepsilon_{k+1}} = \frac{1}{\varepsilon_k} - \frac{1}{\varepsilon_{k-1}} \qquad \textbf{(10)}$$

k having all values between and including 2 and $n-1$

B. If $\frac{\varepsilon_1}{\varepsilon_n}$ is variable, in addition to the variables of case A,

the maximum of V_0 is given by the $n-2$ conditions of case A, and by the added condition

$$l\,n \frac{F_n\,\varepsilon_n\,r_n}{F_1\,\varepsilon_1\,r_0} = 1 - \frac{\varepsilon_n}{\varepsilon_{n-1}} \tag{11}$$

C. If r_0 is variable, in addition to the variables of case B, the maximum of V_0 is given by the $n-1$ conditions of case B, and by the added condition

$$l\,n \frac{F_1\,\varepsilon_1}{F_2\,\varepsilon_2} = 1. \tag{12}$$

The equations derived from these different sets of conditions for the design of graded cables of certain types follow.

I. $n = 2. \quad F_1 = F_2$

A. $$V_0 = F_1\,r_0 \left[\frac{\varepsilon_1}{\varepsilon_2}\,ln\frac{r_2}{r_0} - ln\,\frac{\varepsilon_1}{\varepsilon_2}\left(\frac{\varepsilon_1}{\varepsilon_2} - 1\right)\right]$$

B. $$V_0 = F_1\,r_0\left[\frac{\varepsilon_1}{\varepsilon_2} + ln\,\frac{\varepsilon_1}{\varepsilon_2} - 1\right]$$

$$l\,n\,\frac{r_2}{r_0} = 1 - \frac{\varepsilon_2}{\varepsilon_1} + ln\,\frac{\varepsilon_1}{\varepsilon_2}$$

II. $n = 2. \quad F_1 = \frac{3}{2}F_2$

A. Not derived.

B. $$V_0 = F_1\,r_0\left[\frac{\varepsilon_1}{\varepsilon_2} + ln\,\frac{3}{2}\frac{\varepsilon_1}{\varepsilon_2} - 1\right]$$

$$l\,n\,\frac{r_2}{r_0} = 1 - \frac{\varepsilon_2}{\varepsilon_1} + ln\,\frac{3\,\varepsilon_1}{2\,\varepsilon_2}$$

III. $n = 3. \quad F_1 = F_2 = F_3.$

A. $$V_0 = F_1\,r_0\left[ln\frac{\varepsilon_1}{\varepsilon_2} - 1 + \frac{\varepsilon_1}{\varepsilon_2} + \frac{\varepsilon_1}{\varepsilon_3}\,ln\,\frac{\varepsilon_3\,r_3}{\varepsilon_1\,r_0}\right]$$

$$l\,n\,\frac{\varepsilon_1}{\varepsilon_3} = 1 - \frac{\varepsilon_2}{\varepsilon_1} + ln\frac{\varepsilon_1}{\varepsilon_2}$$

B. $$V_0 = F_1 r_0 \left[\frac{\varepsilon_1}{\varepsilon_3} + ln \frac{\varepsilon_1}{\varepsilon_2} - 1 \right]$$

$$ln \frac{r_3}{r_0} = 1 - \frac{\varepsilon_3}{\varepsilon_2} + ln \frac{\varepsilon_2}{\varepsilon_3} + ln \left[\frac{1}{1 - ln \frac{\varepsilon_2}{\varepsilon_3}} \right]$$

$$\frac{\varepsilon_1}{\varepsilon_2} = \frac{1}{1 - ln \frac{\varepsilon_2}{\varepsilon_3}}$$

IV. $n = 3 \qquad F_1 = F_2 = \frac{3}{2} F_3$

A. $$V_0 = F_1 r_0 \left[ln \frac{\varepsilon_1}{\varepsilon_2} + \frac{\varepsilon_1}{\varepsilon_2} - 1 + \frac{\varepsilon_1}{\varepsilon_3} \, ln \frac{2}{3} \frac{\varepsilon_3}{\varepsilon_1} \frac{r_3}{r_0} \right]$$

$$l \, n \frac{3}{2} \frac{\varepsilon_1}{\varepsilon_3} = 1 - \frac{\varepsilon_1}{\varepsilon_2} + ln \frac{\varepsilon_1}{\varepsilon_2}.$$

B. $$V_0 = F_1 r_0 \left[\frac{\varepsilon_1}{\varepsilon_3} + ln \frac{\varepsilon_1}{\varepsilon_2} - 1 \right]$$

$$l \, n \frac{r_3}{r_0} = 1 - \frac{\varepsilon_3}{\varepsilon_2} + ln \frac{3}{2} \frac{\varepsilon_2}{\varepsilon_3} + ln \left[\frac{1}{1 - ln \frac{3}{2} \frac{\varepsilon_2}{\varepsilon_3}} \right]$$

$$\frac{\varepsilon_1}{\varepsilon_2} = \frac{1}{1 - ln \frac{3}{2} \frac{\varepsilon_2}{\varepsilon_3}}.$$

The results of case *C* may be tabulated, and are shown in Table III.

TABLE III

Type of cable	$\frac{r_1}{r_0}$	$\frac{r_2}{r_0}$	$\frac{r_3}{r_0}$	$\frac{\varepsilon_2}{\varepsilon_1}$	$\frac{\varepsilon_3}{\varepsilon_1}$	$\frac{V_0}{F_n r_n}$
Single layer	2.72	—	—	—	—	0.368
I	2.72	5.11	—	0.368	—	0.531
II	2.72	4.25	—	0.552	—	0.640
III	2.72	5.11	8.18	0.368	0.196	0.626
IV	2.72	5.11	6.26	0.368	0.294	0.817
Ideal grading	—	—	—	—	—	1.000

NOTE 2. Approximate solution for multi-conductor cable.

If a charge of Q units per cm. is considered concentrated along a line having the cylindrical coördinates (d_0, π), the origin being the centre of a sheath of radius R which is at zero potential, the potential function within the sheath is, by the method of images

$$V = -Q \, ln \frac{\rho^2 + 2\, d_0\, \rho \cos\theta + d_0^{\,2}}{\frac{d_0^{\,2}}{R^2}\; \rho^2 + 2\, d_0\, \rho \cos\theta + R^2} \tag{13}$$

The equipotential surfaces of equation (**13**) are circular cylinders whose axes have the coördinates

$$\rho = d_0 \frac{R^2 (1 - c^2)}{R^2 - c^2 d^2}, \qquad \theta = \pi$$

and whose radii are equal to

$$r = R\, c \frac{R^2 - d_0^{\,2}}{R^2 - c^2 d_0^{\,2}}$$

where c equals the base of natural logarithms raised to the $-\frac{V}{2\,Q}$ power, V being the potential of the cylinder in question.

When more conductors than one are placed symmetrically in the same sheath, the potential function may be found approximately by adding terms of the form (**13**), the angle θ being changed to correspond to the position of the new conductors.

DISCUSSION ON "OBSERVATION OF HARMONICS IN CURRENT AND IN VOLTAGE WAVE SHAPES OF TRANSFORMERS", SAN FRANCISCO, CAL., MAY 6, 1910 (SEE PROCEEDINGS FOR MAY, 1910).

(Subject to final revision for the Transactions)

H. J. Ryan: I don't know that there is anything I can add in an effective way to a paper of such great value. Any knowledge of anything that is so fundamental in engineering as the transformer, is of great value, and anything that tends to bring that knowledge up to date, and that has been done in this paper and has been done handsomely, is also of great value.

In the fundamental theory for the treatment of things of this kind use of two principles is made; one is the conservation of energy, and the other is that the average product of two alternating quantities that differ in frequency is zero. Thus by theoretical methods we arrive at the same conclusion, *viz.*, that the harmonics which develop in the exciting current of a transformer do not convey any of the core loss energy.

However, what we come to by theoretical reasoning is generally of very little value until a way has been found to check the result in the laboratory or in practice. It is right here that this paper is of such high value.

The facts brought out in this paper and in Mr. Faccioli's recent tests on a long distance high-tension transmission line show beyond all doubt that it is a matter of great importance to understand properly the causes of wave-form distortion and the methods that should be employed to accomplish their elimination.

We know that a 200-mile, 60-cycle, high-tension transmission line with its receiver circuit open delivers a terminal pressure that is considerably higher than the pressure at the source. With sine wave pressure at normal frequency applied at the source this terminal pressure rise will be a certain amount. Now assume the use of a non-sine wave source pressure made up of one part at normal frequency and a second part at ten per cent of the value of, and at a frequency of three times the first part, being different in frequency each of these pressure parts will work upon the line independently to produce a rise in the terminal pressure. The rise in value and shift in phase will be much greater in proportion for the third harmonics than the fundamental. The result will be to change and to distort greatly the wave form of the open circuit terminal pressure. There will be a corresponding increase in certain instantaneous values of the pressure accomplished by increase of the electric strain on the insulation and such other disorders as follow because of the use of the irregular wave forms.

Mr. Faccioli's transmission experiments and investigations have checked the above theoretical reasoning. It is, therefore, decidedly evident that all wave distortions introduced by three-phase source star-connected transformers, neutrals free, or by

any other means should be carefully avoided in high-tension long distance transmission.

G. Faccioli: Professor Ryan brought out the point of the influence of harmonics on the core losses.

Th s is a very interesting problem. It is true that the high frequency component of the exciting current of a transformer is wattless, but I do not agree with the author of the paper in his conclusion that the distortion of the current is neither a cause nor an effect of the energy loss in the core.

The figures below are respectively a reproduction of Fig. 9 and Fig. 10. The straight line *a* is the loop obtained by plotting the values of the flux in function of the values of the wattless component of the fundamental of the exciting current. This condition of affairs would be possible if we used in the transformer core a material of constant high permeability. Curve *b* is

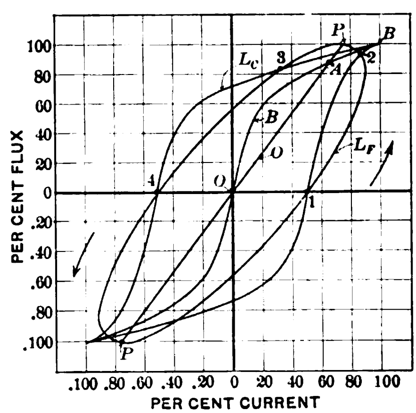


FIG. 9

obtained by taking as absc'ssæ the values of the fundamental and harmonics of the excit ng current in phase with the flux. Both *a* and *b* presuppose no losses, but while *a* assumes constant permeability, *b* admits a change in permeabi ity.

It is interest'ng to note that the line *a* crosses the curve *b* in one point only, *A*. This means that if we increase the flux from zero to maximum positive in the case of constant permeability and no losses, the current should be a sine wave in phase with the flux. If the permeability is not constant, then while the flux increases from zero to the point corresponding to *A*, the values of the current are smaller than the values of the sine wave. From the point corresponding to *A* to the maximum value of the flux *B*, the current 's higher than the values of the sine wave. Decreasing the flux from maximum positive to zero, we repeat the phenomenon in a reverse direction.

It follows that the change in permeability has caused the

current to be less than the value of the sine wave for part of a half cycle; then for another part of a half cycle the current becomes higher than the values of the sine wave, and finally, for the rest of the half cycle, the current is again smaller than the sine values. It is apparent, therefore, that the distortion of current introduced by the change of permeability, crosses the zero line in two points during a half cycle, and is symmetrical with respect to a vertical axis drawn through the maximum value of the flux.

The change of permeability introduces then a high harmonic in the current, whose fundamental wave is of triple frequency. This does not mean that this extra current is a triple frequency sine wave, but it shows clearly, in my opinion, that the disturbance has a large triple frequency component, and is symmetrical with respect to the flux wave.

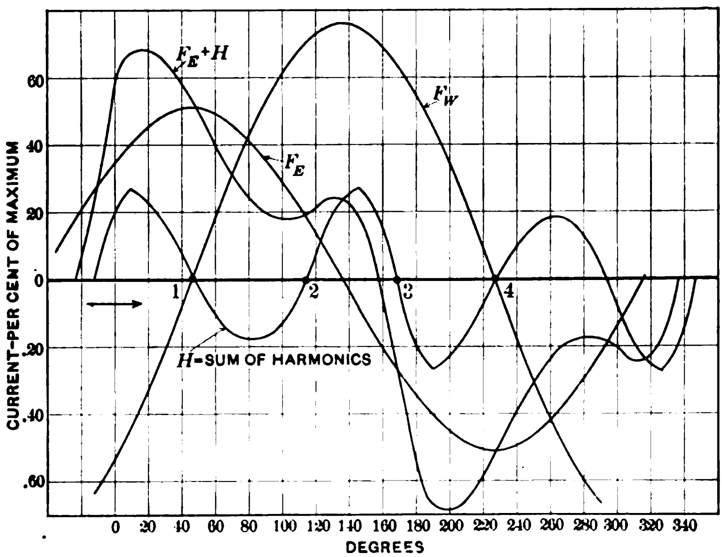


FIG. 10

If now, we take losses into consideration, the line *a* is expanded into an ellipse, and the curve *b* becomes the regular hysteresis loop.

Following the same reasoning as before, we see that in the first quarter cycle of the flux (while the flux grows from zero to maximum positive) the hysteresis loop, starting from point 1, crosses the ellipse at the point 2. It follows that from 1 to 2, the presence of the iron causes the current to be less than the values of the sine wave, (Fig. 10.) From 2 to 3, the current is larger than the sine values, and finally from 3 to 4, the extra current introduced by the iron has again negative values.

It follows immediately that the total distortion introduced by the iron, including losses, is fundamentally of triple frequency, as in the former case, where losses were neglected, but when losses are considered, the distortion is no longer symmetrical with respect to the vertical axis drawn through the maximum value of the flux, as shown by the unsymmetrical position of the points two and three.

We may therefore draw the conclusion that the presence of losses has modified the distortion of current, which would be introduced by a mere change of permeability. The high frequency components of the current are wattless for the whole cycle, but they are active in distributing the losses throughout the cycle, and part of the distortion is a consequence of the presence of these losses.

It seems to me that a glance at Figs. 9 and 10 will show why the distortion of the current due to iron is fundamentally a triple frequency wave. It shows, furthermore, which is the phase position of the high frequency waves. In fact, if we locate such phase position with respect to the flux wave, we see that at points 1 and 4, which are the points of zero flux, the value of the resulting high frequency wave is zero. This is shown in Fig. 10 where the curve *h*, which is the sum of the harmonics, crosses the zero line at the zero point of flux. This happens also in Fig. 12.

In conclusion, it appears clear why the high harmonics introduced by the iron are fundamentally of triple frequency, and it is easy to find their phase position, if they are referred to the wave of flux.

W. A. Hillebrand: Mr. Faccioli's conclusions, that the presence of the higher harmonics, redistributes the losses, strikes me as self-evident. In any circuit it is impossible at any time to know of both currents electromotive forces without having power. It simply means that the term wattless current for wattless volt-amperes, and that the voltage of the other products throughout, is fundamentally higher, and in that instance is zero.

C. A. Copeland: All of this discussion has been based on the assumption that we start out with a sine curve. It would be rather interesting to find out either theoretically or practically what are the worst conditions we would find by starting out with a curve which was a little flat topped or peaked. I was wondering whether there had been any oscillograms taken, starting out with either a flat top or peaked top wave, so as to show what the worst condition would be that we might have, under these conditions.

G. Faccioli: Of course, in a paper of this kind, it was necessary to apply sine waves to the transformers in order to obtain comparable results.

We can deduce the effect of the wave form on the triple frequency component of the exciting current by remembering that in a Y-connected system (neutral disconnected, secondary open) the electromotive force across each individual transformer

is distorted as a consequence of the fact that triple frequency currents cannot flow in the Y.

Then, if we apply to a transformer an electromotive force, as the one represented, for instance, in curve **17**, sheet **4**, we must expect that this electromotive force will not call for a triple frequency exciting current. Now this electromotive force contains a triple frequency conponent itself. If we reverse this component **180** deg., we should expect to reach the conditions where the triple frequency exciting current will be maximum.

President Stillwell: I think it might be interesting if you would explain to what extent the use of the silicon steel affects the triple frequency current.

G. Faccioli: The new silicon steel has a hysteresis loop which is different from the loop of iron used previously. It is well known that the losses per cycle are smaller, and that the permeability at high densities is lower in the silicon steel. We should then naturally expect a somewhat different distortion of exciting current due to silicon steel.

C. L. Cory: It is interesting to contrast the methods which Professor Ryan used twenty years ago in obtaining the curves, point by point, not upon single waves but upon succeeding waves, using a 133-cycle generator, with the results that are shown in the paper read to-day. The three papers, that of Professor Ryan twenty years ago, that of Mr. Rhodes read yesterday, and this paper of Mr. Frank's presented to-day are all of the same type, and the results obtained from the experimental work done are of great value. The things that Professor Ryan really discovered are the things that have now been completely developed and are so clearly shown in the oscillograms so well reproduced in the paper.

From what we heard yesterday morning and also here to-day it is possible that we may conclude that the third harmonic and the higher harmonics, the fifth, seventh, ninth, etc., introduce only difficulties in connection with the generation and use of alternating currents. I do not believe that that conclusion necessarily follows. It was shown yesterday by Mr. Rhodes that the triple and higher harmonics are produced by generators under certain circumstances and this morning by Mr. Frank it has been shown that, no matter what kind of a curve we start with from the generator, somewhere in our transmission system we will find the conditions which are shown by these curves and we cannot avoid the distortion from the true sine wave.

The presence of the higher harmonics have been found troublesome and have almost always lead to difficulties. To-day in the transmission of power we are still using a relatively high frequency. From the beginning of the use of alternating currents the frequency has been reduced from 133 to 120 cycles down to 60, 50, 40 and even 25 cycles, and when we begin to transmit still larger quantities of power over distances three or

four times as great as ordinarily found at the present, or up to 500 or 600 miles, perhaps lower frequencies such as 10 $12\frac{1}{2}$ or 15 cycles will be found, under certain circumstances to be decidedly preferable.

Is it not possible therefore as the art of the generation and application of electricity still further develops that we may generate by a single generator currents of more than one frequency, or, what would be equivalent, one current of two or more frequencies? We really produce such currents in the generators that were described by Mr. Rhodes, although we do not want them, and as shown by Professor Bedell greater economy of copper results when two currents of differing frequencies are transmitted over the same conductor, and ultimately we may to advantage make use of the combination for more efficiently transmitting power than is possible using current of only one frequency in each conductor.

Silvanus P. Thompson (by letter): Mr. Frank's paper is of particular interest to me, because I happen to have just prepared for the Physical Society of London a yet unpublished note on Hysteresis Loops and Lissajous Figures, the substance of which is as follows. Just as any wave curve, whether of current or of voltage, can be analyzed according to Fourier's theorem into a harmonic series of sine and cosine terms containing only odd terms in the series, so any hysteresis loop can be analyzed into a harmonic series of Lissajous figures, (in sine and cosine terms) containing only odd terms in the series.

The area of the hysteresis loop represents the energy spent in a cycle of magnetizing operations. If we represent the impressed electromotive force as a sine-function of the time, it is known that the wave-form of the flux will be a pure cosine function of the time, and that the wave-form of the reactive electromotive force will be a pure (negative) sine function of the time. Now, if there are present hysteresis and eddy-currents, the current curve will, as known ever since Ryan's classical researches of 1890, not have a simple wave form. It may contain terms of the following orders:

1. $A_1 \sin p\,t$
2. $B_1 \cos p\,t$
3. $A_3 \sin 3\,p\,t$
4. $B_3 \cos 3\,p\,t$
5. $A_5 \sin 5\,p\,t$
6. $B_5 \cos 5\,p\,t$

with possibly other terms of higher orders. Now as the impressed voltage has a form expressed by $V_1 \sin p\,t$, the total energy expended in a cycle will be represented by the result of multiplying $V_1 \sin p\,t$ into each of the above terms, and integrating each such product around a whole cycle, or from $t = 0°$ to $T = 360°$. But, as is well known, the following integrals all have zero value if integrated over a whole period:

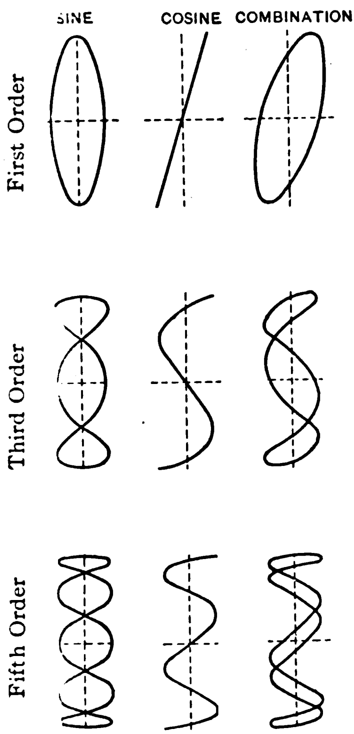
$$\int \sin pt \cos pt,$$

$$\int \sin pt \sin n\, pt$$

$$\int \sin pt \cos n\, pt;$$

where n is any whole number. The only product that remains is therefore the fundamental, *viz*:—

$$\int_0^T \sin^2 pt$$



That is to say the only component which involves the expenditure of any energy in the cycle is the sine-component of the first order; that is so much of the current wave as in phase with the impressed voltage. All other components may distort the form of the current wave, and therefore of the hysteresis loop, but alter the amount of the area of the loop in nowise. The area of the loop is equivalent under all cases to that of an ellipse, the principal axes of which are respectively the maximum flux-density the value of $\mathcal{H}$ due to the maximum value of the first-order sine component of the current curve.

The effect of magnetic leakage, or of an air-gap in the iron core is to shear over the hysteresis loop, that is to introduce as a component a first-order cosine term.

The above are the Lissajous figures which correspond to the several terms:

The total areas of Lissajous figures, of all orders except the first is zero; their negative and positive portions being always equal.

Eddy currents will invariably give sine-components of the first order, and add a further elliptical component to the ellipse. Eddy-currents of the third order, which will be present only if there are third order components in the voltage curve, will tend to distort in the form containing both sine and cosine components of the third order, resembling the letter S.

The ordinary hysteresis loops with acute peaked forms at their ends, obtained when the flux-density is pushed to high values, contain negative cosine terms of third, fifth, and higher orders, and cannot be adequately represented without going to terms higher than the eleventh.

I am able to confirm Mr. Frank's conclusion that the distortion of the form of the current wave curve is neither a cause nor an effect of energy loss in the core, but depends only on the variations of the permeability of the steel.

May I be allowed in conclusion to express my gratification that so much utility has been found by Mr. Frank in the employment of my arithmetical method of harmonic analysis, itself derived from that of Professor Runge of Hanover. I desire to thank him for the exposition of it which he has given.

Edmund C. Stone (by letter): I have made a number of oscillograms on a three-phase core type transformer with star-connected primary, which check those given in the paper. The wave form impressed was somewhat flatter than a sine wave and the effect of this in peaking the phase voltage was very marked.

If three single-phase transformers in star are connected to a three-phase generator and the neutral of the transformer is connected to that of the generator, the conditions in the transformers are the same as if each was alone on a single-phase circuit; the magnetizing current having its characteristic shape in each transformer. The neutral is the return circuit for all the transformers, so that the instantaneous values of its current are the sum of the instantaneous values of all the magnetizing currents. It carries all of the third harmonic components of the single-phase currents, which add to each other numerically, since in a symmetrical three-phase system the third harmonics all have the same phase. Now imagine for a moment that an e m.f. could be impressed on the neutral which would cause a current to flow exactly equal and opposite to the current already in the neutral. Such a current would divide and flow in the same direction through the transformers thus cancelling out the third harmonic component of the single-phase magnetizing currents. The current in the neutral would then be equal to zero and the neutral could be opened without changing the conditions in any way. Hence it will be seen that when the transformers are star connected w th the neutral open, a current of tr ple frequency is present in each one which is of the same phase in all three transformers and is *subtracted* from the single-phase magnetizing current, thereby eliminating from the latter its third harmonic. This current, of course, sets up a flux of triple frequency and same phase in all the cores, which subtracts from the single-phase flux and introduces a third harmonic into the counter e.m.f. wave accordingly. Such a third harmonic increases the maximum value of the phase e.m.f. but does not appear at the terminals of the star-connected windings. When

the secondaries are connected in series or delta, however, the triple frequency components of voltage are in phase and add to one another, thus producing an unbalanced e.m.f. around the delta. When the delta is closed this voltage becomes practically zero and a current flows which is equal to that producing it; that is the third harmonic of the single-phase magnetizing current has been transferred from the primary where it cannot flow, to the secondary where it can flow through the closed delta.

In the case of three single-phase transformers, the flux set up by the triple frequency component of magnetizing current has the same circuit as the main flux, that is, the core of the transformer, which being of exceedingly low reluctance, permits considerable flux to be set up, thus causing great distortion to the wave form of the phase e.m.f. (as shown by sheet No. 13). In the case of the three-phase core type transformer, however, this triple frequency flux cannot pass around the main circuit, since it would then be opposed by the flux of another phase. The result is that it must find a return path through air or the case and end frames. This local circuit has necessarily a high reluctance so that only a small flux is set up by the third harmonic current and the wave form of the phase e.m.f. is only s ightly distorted.

C. Fortescue (by letter): This paper shows very clearly the necessity of considering the wave forms of generator e.m.fs. of transformer exciting currents, etc., with reference to their effect in polyphase circuits.

The writer during the past few years, has been frequently called upon to explain phenomena due to such causes and many of his conclusions are corroborated by the data given in Mr. Frank's paper and his explanation of them.

Referring to Mr. Frank's discussion of interconnected transformers: it is shown that if the third harmonic component of the exciting current is prevented from flowing by the method of connecting the transformers, a third harmonic component of e.m.f. will appear in the transformer windings, which will increase the insulation stress throughout the transformer. It may be well to remark that the effect would not be so marked in ordinary commercial transformers as for the case given, since the iron is not usua ly run at so high a density as 90 kilo-lines per square inch.

In star-delta connected transformers, a third harmonic component flows in the delta windings, which is the exact equivalent of the missing third harmonic component of the exciting currents in the star connected primary. If the primary line to line e.m.f. is not a sine wave, it may contain any odd harmonic but the third and its multiples, provided that all three waves of e.m.f. from line to line are similar in form. Each of the harmonics in the three phases are in proper three-phase relation and will also appear in the neutral to line e.m.f. across the transformers. But where the effect of these harmonics may have been to peak

the wave form from line to line, their effect will be to flatten the wave form across the transformers, that is, from neutral to line, the converse of this also being true. We should therefore expect to find that with star-delta connected single-phase transformers, a peaked e.m.f. wave form from line to line would result in a higher iron loss in the transformers than that obtained with a corresponding single-phase sine wave measurement. And similarly, if the line to line e.m.f. wave form is flattened, the observed iron loss should be less. Perhaps this may be the explanation of the difference in iron loss observed by Mr. Frank, when measured single-phase and three-phase. with neutral disconnected and delta closed.

In sheet No. 10 of Mr. Frank's paper, we have a triple harmonic 0.63 amperes occurring in the secondary delta connection. Multiplying this by the ratio of transformation, we have for the corresponding primary single-phase, third-harmonic component, 3.15 amperes, and the equivalent single-phase exciting current is, therefore, $\sqrt{5.81^2+3.15^2} = 6.6$ amperes. This is 10 per cent higher than the value found for single-phase, namely 6.05 amperes. The cause of this apparent discrepancy is probably due to the wave form of the line to line e.m.f., which may be somewhat peaked, thereby resulting in a flattened e.m.f. wave form from transformer neutral to line, and therefore a higher exciting current and iron loss.

The third harmonic is not present in the line to line e.m.f. of symmetrically wound three-phase generators, but it occurs in the e.m.f. of two-phase generators and, therefore, it will appear also in three-phase e.m.fs. obtained by transformation from two-phase. The wave forms of line to line e.m.f. in such cases are not similar. Such a system may be considered as made up of a symmetrical system on which is superimposed a third harmonic three-phase system. If such a system is connected with a true three-phase system, this three-phase third harmonic component may be the cause of grave trouble.

In conclusion, the writer would like to see more data as to the effect of different polyphase connections on the iron loss of the transformers, to supplement Mr. Frank's valuable contributions.

C. A. Adams (by letter): The immense amount of data gathered by Mr. Frank on this important and interesting subject, is almost staggering, and it is quite impossible to do justice to it in a limited discussion. A somewhat careful reading developed the necessity for some additional explanations and amplifications which are here presented with the hope that they may help others similarly interested.

The area of the loop *L C*, of Fig. 9, respresents the eddy current loss as well as the hysteresis loss and the loop is broader abeam than the true hysteresis loop. The eddy current energy is supplied by a current component in phase with and of the same shape as the impressed e.m.f., and the real hysteretic

energy current is equal to F_E less this eddy current component, with which it is in phase.

The relative values of the maximum inductions of the various harmonics are not the same as the relative values of the corresponding e.m.fs. since the induction is the integral of the e.m.f. and therefore involves its frequency as well as its amplitude; *e.g.*, if the third harmonic e.m.f. is 52 per cent of the fundamental e.m.f., the third harmonic flux is only $17\frac{1}{3}$ per cent of the fundamental flux.

For the purpose of explaining several points in connection with the oscillograms, it will be desirable to review briefly the various transformer connections.

In every case it is assumed that the impressed e.m.f. is balanced, symmetrical, sinusoidal and 3 phase; also that a third and a fifth harmonic exciting current are necessary for a sinusoidal flux.

Three Separate Transformers, Primaries Star, Secondaries Delta

1. *Isolated Neutral—Open Secondary Delta.*

The third harmonic exciting current cannot be supplied, therefore, The flux must contain a third harmonic, such that it would require for its m.m.f. a third harmonic current equal and opposite to the third harmonic current that would be required by the otherwise sinusoidal flux.

The star e.m.f. will then contain a corresponding third harmonic and the voltage across the open neutral will be three times the third harmonic phase e.m.f., since the three are all in phase.

The fifth harmonic exciting current will appear in the primary since the three fifth harmonic currents neutralize each other just as do the fundamentals.

The three third harmonic e.m.fs. in the secondaries will add together and appear across the open delta, thus the open delta voltage should differ from the open neutral voltage only by the ratio of transformation.

2. *Isolated Neutral—Closed Secondary Delta.*

As soon as the delta is closed the third harmonic e.m.f. in the delta will produce a third harmonic current which will supply the previously missing third harmonic exciting current and restore the flux to the sinusoidal form; but this flux cannot be quite sinusoidal since there must be a small third harmonic e.m.f. in the secondary to produce the third harmonic exciting current.

The phase e.m.fs. are therefore sinusoidal barring this very slight third harmonic, and the voltage across the neutral is practically zero.

The fifth harmonic exciting current will appear in the primary as in (1).

3. *Connected Neutral—Closed Delta.*

If the slight third harmonic in the phase e.m.fs. were to retain the same value as in (2) there would now result third harmonic currents in the primaries of approximately the same m.m.fs. as those of the third harmonic current in the secondary delta; but this would reverse the third harmonic flux and is obviously impossible. *I.e.*, the total third harmonic exciting current in primary and secondary cannot appreciably exceed its previous value in (2). Therefore, since the third harmonic e.m.f's in primary and secondary are equal, as well as the local impedances of the circuits in which the e.m.fs. act the third harmonic current will be divided evenly between primary and secondary, thus requiring only one half of the third harmonic flux and phase e.m.f. of (2).

However, if there be ever so small a third harmonic in the impressed phase e.m.f., it may (if in the proper phase) *just* supply the impedance drop of the necessary third harmonic exciting current, and entirely elim-

inate any need of even the slightest third harmonic flux and secondary phase e.m.f.

Then no third harmonic exciting current would appear in the secondary delta, as it would all appear in the primary.

If however the slight third harmonic in the impressed primary phase e.m.f. be of the opposite phase, it will drive the exciting current to the secondary delta by causing an increased third harmonic flux and secondary phase e.m.f.

This last is the reason why in some of the oscillograms (taken with connected neutral and closed delta) the third harmonic exciting current appears in the secondary delta, and sometimes in the primary and neutral, and sometimes in both.

Curves 69 and 70, sheet 11, analyzed in Figs. 24 and 25, show a small third harmonic exciting current in the primary lines and neutral, but as the third is less than the fifth it is reasonably certain that the larger part of the third is to be found in the closed delta, although no oscillogram thereof is given. The fundamental, fifth, seventh, and eleventh harmonics in curve 70, Fig. 25, are due to an unsymmetrical system, as they would otherwise cancel out.

The curves of sheet 2 also show the harmonic exciting current divided between the primary and secondary for the same case of connected neutral and closed delta, the larger part being in the primary, while for the case of sheet 11 the larger part was in the secondary.

4. *Connected Neutral—Open Secondary Delta.*

In this case each transformer is entirely independent and the exciting current will flow in the primary as in the case of a single transformer with sinusoidal impressed e.m.f. and open secondary.

The three third harmonic exciting currents will add together in phase in the neutral while the fundamentals and fifth harmonics cancel out.

If the impressed e.m.f. on each transformer is absolutely sinusoidal, the induced e.m.f. and flux will be distorted an imperceptible amount by the internal impedance drop due to the third and fifth harmonic currents, and there would be a very slight third harmonic e.m.f. across the open delta, the fifth cancelling out with the fundamental. These are, however, too small to be of any practical importance.

The considerable third harmonic e.m.f. across the open delta in curve 15, sheet 3, must be due to a third harmonic in the impressed e.m.f.; a careful inspection of curve 12 will show this to be the case.

Curve 75 of sheet 12 also shows a third harmonic e.m.f. in the secondary for this same connection, but in this case it is only $\frac{1}{4}$ per cent whereas in curve 15 it is 5 per cent. In this case (curve 75) it may therefore be partly if not largely due to the e.m.f. distortion produced by the large third harmonic current in the primary.

One Three Phase Transformer

If the three cores are *absolutely symmetrical* and the impressed e.m.fs. balanced, there can be no third harmonic flux in the main magnetic circuit. Any such flux in the core legs must return *via* the surrounding non-magnetic material; *i.e.*, the re-

luctance of the third harmonic flux path is many times that of the fundamental flux path.

1. *Isolated Neutral—Open Delta.*

In this case there can be no third harmonic exciting current, therefore there must be a third harmonic flux of sufficient magnitude to eliminate the need of a third harmonic exciting current; *i.e.*, a flux which would require for its m.m.f. a current equal and opposite to the third harmonic current that would otherwise be present. But the reluctance of the third harmonic flux path is so large (as explained above) that a negligibly small third harmonic flux is sufficient to neutralize the third harmonic current. Thus it is that the leg e.m.f. is practically sinusoidal and the voltages across the open neutral and open delta are zero, in spite of the fact that there is no third harmonic exciting current, see Sheet 21.

It is obvious that closing the neutral or the delta or both would have no appreciable effect upon the curves, as is shown on sheets 18, 19 and 20.

In a similar manner numerous other interesting points can be explained.

J. J. Frank: The paper was prepared primarily for the benefit of operating engineers to emphasize the great practical value of an investigation of the distortion of current and potential wave shapes found in the common banking of transformers. The absence of any discussion by operating engineers is somewhat of a disappointment.

The confirmation by Sylvanus P. Thompson of my conclusion that the current wave distortion depends only on the variations in the permeability of the steel is very gratifying.

The discussion by C. A. Adams, calling attention to the possible amplification of the data submitted in my paper, is also very gratifying.

DISCUSSION ON "PARALLEL OPERATION OF THREE-PHASE GENERATORS WITH THEIR NEUTRALS INTERCONNECTED". SAN FRANCISCO, CAL., MAY 5, 1910. (SEE PROCEEDINGS FOR MAY, 1910.)

(Subject to final revision for the Transactions.)

H. J. Ryan: The author of this paper defines the factors that cause undesirable currents to circulate among the common neutrals of large Y-connected alternators operated in parallel. He develops analytically the relations of those factors so that the magnitude of the circulat ng currents may be predetermined with a fair degree of accuracy. To be able to do this is half the battle that must be fought to reduce them to harmless proportions.

In the Interborough and similar plants, the alternator neutrals are paralleled and grounded so that an underground cable feeder in which a fault through the insulation to ground develops will be automatically d sconnected before the fault grows into a complete and destructive short circuit. This mode of operation developed troublesome circulating currents among the paralleled neutrals of the alternators. The remedy finally adopted was to ground the neutral of but one alternator. in each of the two Interborough stations operating in parallel. The proportions employed in setting the feeder circuit-breakers, resistance of ground connections, etc., are such as to secure maximum effectiveness of the protection thus accorded the underground system.

This eliminates the paralleled neutrals and constitutes one remedy that has been put into practice with rather good results.

At the close of this paper the author proposes two additional remedies:

1. The distribution of each armature phase over 120 deg. fundamental, in lieu of 60 deg.

Each pair of actual or fundamental poles have as third harmonic components six small poles. These proposed broad armature coils cut such third harmonic poles in opposing pairs. Phase opposition occurs in developing the corresponding third harmonics e.m.fs. with a net result of zero for such e.m.fs., no matter to what extent the third harmonic poles may be produced by armature reaction.

2. A uniform distribution of air-gap reluctance and a polar distribution of fie d excitation m.m.f. so as to match the distribution of armature reaction m.m.f.

This practically implies an alternator modeled structurally much like an induction motor or generator.

These are features that the factories can very likely find a way to meet. Doubtless generators of this character should be somewhat less desirable in other respects, because they are not now found in practice. As against the compromise method now in use designated above as No. 1, is either method, No. 2 or No. 3, desired sufficiently to offset the manifest disadvantages

that must exist somewhere for the reason just given? One hopes that the discussion of this paper will throw some light hereon.

The author of the paper has done the profession a real service in demonstrating that all problems which owe their origin to non-sine wave conditions may be solved by the sine-wave methods applied to the multi-frequency components of the original irregular alternating waves. The method looks complicated because of the many terms that the several frequencies introduce. Inherently it is nothing more than an extension of our common methods.

S. J. Lisberger: In paralleling the two alternators, Mr. Rhodes speaks of alternating the two; does he leave the neutral of the alternator that is to be grounded, when the two are in final parallel, open until the two are synchronized, or is it closed at the moment of synchronizing the two alternators?

G. I. Rhodes: We have little occasion to parallel two generators with their neutrals interconnected. Normally, one unit in each plant is connected to the neutral bus. When this grounded machine is to be taken out of service the neutral of a second is grounded and then that of the first cleared. This procedure allows the two machines to run for a short time with their neutrals in parallel.

When the two stations have to be synchronized the operation is performed with the neutral of each grounded. The rheostats however, limit the interchange of current to a small value.

The primary object of the ground resistance is to limit the flow of current to a grounded cable. This is the sole object where a single rheostat is used. Where a separate resistance is inserted in the neutral connection of each generator it has the added function of greatly reducing the interchange of triple harmonic currents between machines.

C. L. Cory: On the Pacific Coast we have had some experience in operating high-voltage Y-connected generators, and the resultant higher harmonic e.m.fs. There are one or two things I may add to the paper, not so much regarding the operation of the generators in the station but the results on outside circuits of grounding the neutral.

There are in the Redondo Station of the Pacific, Light & Power Company three 5000-kw., 18-000-volt, Y-connected generators directly driven by reciprocating engines and during a fifteen day test of one of the units, as well as during the regular operation of the plant, the presence of these higher harmonics was observed in a manner somewhat similar to that outlined in the New York station. I do not know exactly what was done regarding the neutral connections to the ground after the test was completed, but during the test ammeters were connected in the neutral circuit to the ground from each of the three generators. It was observed that the ground currents varied with the relative loads upon the generators.

I do not recall at this time what arrangement was made regarding the neutral connections during the synchronizing of the generators, but the three generators were operated in synchronism during the test and the plant as a whole was run in synchronism with water power and other steam driven stations many miles away.

One thing which was observed, of which you unquestionably have knowledge in the operation of such machines, was the impossibility of connecting the secondaries of the transformers in delta with their primaries connected Y since there is a current due to the e.m.f. of the higher harmonic waves wh ch manifests itself in the delta connection of the secondary side. There is another point, and if I am wrong, Mr. Rhodes, I will be very glad to have you correct me, is that the magnitude of the current from the neutrals to the ground due to the higher harmonics, principally the third, depends directly upon the voltage of the generators.

G. I. Rhodes: Yes. The current flowing to ground on account of the electrostatic capacity of the lines is directly proportional to the voltage. The interchange of current between machines is the same proportion of full-load current irrespective of the voltage.

C. L. Cory: Therefore, if we should reduce the voltage of these generators from 18,000 volts down to 2300 volts the magnitude of the ground currents would be correspondingly reduced, which reduction of voltage, while not a complete solution, would reduce the trouble.

The principal difficulty which was found in this case was the interference with the telephone and telegraph lines wherever there was an exposure of such circuits near the high-voltage transmission lines connected with the system. Telephone lines that operated very satisfactorily before the neutral was connected with the earth were, after this connection was made at the station, practically rendered inoperative. We have here to-day, Mr. President, the engineers of the telephone company and since they have to a great extent inoperative the conditions produced by the operation of high tension transmission systems on the coast, this side of the matter should I think be given due considerat on. It is apparent, as set forth in Mr. Rhode's paper, that telephone and telegraph line interference may be of considerable magnitude during the time when the generators are being started and synchronized and that the conditions would not be so severe during the normal operation of the generators, although with the changing loads on the generators serious troubles might be encountered.

In this connection it is worth remembering that very little difficulty, comparatively, has resulted from grounding the neutrals of the 60,000 volt and 100,000 volt transmission lines where the generators are operated at comparatively low voltage and the high line voltage is obtained by step-up transformers.

There is another instance in Southern California where a large steam turbine with a Y-connected high-tension generator had the neutral grounded. In this case the higher harmonics interferred seriously with the operation of the telegraph system. the telegraph and transmission lines running parallel along the right of way of the Southern Pacific Company for a number of miles.

In the general solution of the problems which have arisen and will continue to arise in connection with transmission lines and telegraph and telephone lines, there is no question but that the equations and discussions as set forth in the paper, as well as the conclusions of the author, will be of material advantage.

President Stillwell: I would ask Mr. Rhodes whether he, during his investigation, measured or approximately measured the variation.

G. I. Rhodes: No such measurements have been made.

President Stillwell: Did you form any impression as to whether the variation in angular velocity in the case of the reciprocating engine was quantitatively a serious matter as affecting the interchange of current? In other words, is there serious disadvantage, in your judgment in using a reciprocating engine as compared with a water or steam driven turbine, assuming that armatures are similarly wound?

G. I. Rhodes: The difficulty of operating the plant with the neutrals in parallel was due primarily to the variation in angular ve ocity of the engines; the trouble during the operation of synchronizing could have been avoided by closing the neutral afterwards. Where turbines are used there is no appreciable surging in the neutral connections.

It is possible to introduce triple harmonic current by unequal excitations, but under normal conditions these currents are negligible.

President Stillwell: The point I have in mind is, would the variation of angular velocity, in the case of a winding having two slots per phase per pole, be serious from a practical operating standpoint?

If you had *no* third harmonic would it be serious?

G. I. Rhodes: The number of slots per pole has no direct influence on the neutral current. If the alternators had been designed to be without triple harmonics under all conditions of load, the variations in angular velocity would not have been serious. It would have been possible to operate the machines with their neutrals in parallel, without any interchange of current other than that which would occur with the neutrals disconnected.

C. F. Adams: In connection with this question, I do not think the question of circulating currents in grounded neutrals has ever been an issue as far as the apparatus of the Pacific Gas and Electric Corporation has been concerned until possibly within the last few months. Many of the generators at the power stations are Y-connected, others are delta-connected. I don't think

the question of the circulating current in neutrals has ever become anything of a factor. At the Oakland station the high potential transformers are of course star-connected on the 2,300-volt side. With synchronous motors of the Stanley type, running connected in the same manner with grounded neutral, there is absolutely no flow of current through the neutral that is noticeable. With the turbines floating on the line, there is no appreciable flow of current through any of the meters, but there is present a circulating current through the neutral of approximately 300 amperes. The speed of the turbines is 720 revolutions, and with practically all of the rest of the system being water-driven, this question of angular velocity would not seem to be much of a factor. I think the matter of current flow is probably due to the variation in the type of pole face used in the generators. That is my opinion and belief at the present time. Mr. Downing has made some experiments in that line, and possibly he can give us some information.

Paul Downing: We have made some tests along the lines which Mr. Adams has indicated, but have not as yet reached any definite conclusion. We have a circulating current there, which is practically constant, regardless of the load carried by the turbines. This particular turbine runs in connection with the transmission line, which is supplied with power from hydro-electric plants. A great deal of the time that particular turbine carries no load, simply floating on the line. As I say, we have not progressed quite far enough with our experiments yet to arrive at any definite conclusion.

Along this same line I would ask Mr. Rhodes if it is common practice to operate different stations in parallel on a given network, and if so, whether or not the current on the neutral of one machine in each station, or one machine, feeds in to a given network.

G. I. Rhodes: The system with which I am connected, consists of two plants operated in parallel with a single generator in each station grounded through a resistance. These resistances practically eliminate trouble from the neutral currents. There is no reason why a network having several power stations could not be operated in this manner.

E. F. Scattergood: Mr. Rhodes speaks of several machines operating in parallel and suddenly one of these machines dropping out. I would ask if that occurs with the turbines or only with the reciprocating engines, or with both?

G. I. Rhodes: There was no definite indication of why a machine would drop out suddenly. It was probably due to the valve motion on the engines. When the machines were operated in parallel with their neutrals interconnected, the surging was very irregular. At times an especially heavy surge would occur on a machine without cutting it out, but this was frequently a preliminary signal of trouble. There should be no trouble of this kind in steam-turbine or in hydraulic plants.

W. F. Lamme: I would like to ask about the regulation of the machine. I have had some experience in paralleling alternators and have noticed that where a machine would run perfectly parallel up to 400 volts, at 2000 volts you could not get satisfactory work out of it at all.

G. I. Rhodes: The inherent regulation of these generators figures out at about four and one-half per cent.

P. M. Lincoln: My judgment of the value of this paper is based entirely upon the conclusions which are mentioned in the last few paragraphs and particularly to the one conclusion which is mentioned in the first sentence of the concluding paragraph. This reads as follows:

> In conclusion then it appears that alternators as usually designed and built are not suited for parallel operation with their neutrals interconnected.

Judging from this it seems that Mr. Rhodes has attempted to demonstrate something contrary to actual facts.

I am familiar with the designs and practice of alternating-current generators as made by the company with which I am connected, and quite a considerable number of the generators made by this company has been operated on four-wire three phase systems with the neutrals of the generators solidly connected to the neutral of the system operated, thus forming the systems with interconnected neutrals such as Mr. Rhodes discusses. In no case where such practice is in use has any particular attent'on been paid to the design of the generators with a view of reducing any disturbances which might arise from these interconnected neutrals. In the operation of such generators as have been used with interconnected neutrals there has never been any reason for complaint on account of this connection with the single exception of the plant with which Mr. Rhodes is connected. In view of the fact, therefore, that quite a large number of plants are using this method of operation and the further fact that this method is becoming more and more popular as time goes on, I do not think that Mr. Rhodes' broad conclusion is in any sense justified.

The question of circulating currents between various generators operated in parallel is by no means a question of the generators only. The prime movers which operate these generators have a great deal more to do with the magnitude of these circulating currents than has the generator itself. In any plant where alternating current generators are paralleled, currents are bound to circulate between the various units in parallel. The magnitude of these circulating currents is dependent to a very large degree upon the uneven driving torque which is a necessary accompaniment of reciprocating engines. It is well known that the power output of any reciprocating engine is not constant at all times. It rises to a maximum at the beginning of the piston stroke when the pressure within the cylinder is nearly boiler pressure and falls to a minimum at the end of the stroke,

when there is no effective pressure within the cylinder. On the other hand the power output of an electric polyphase generator into its circuit is constant, and is the same at each instant of time. The average power output of an engine is equal to the average power output of the generator plus the losses. The excess or deficiency of power in the engine cycle therefore is devoted to two things—first, the speeding up or slowing down of the flywheel which is attached to the generator, and second, a somewhat increased or decreased power output from that particular generator on account of the fact that its e.m.f. wave is forced somewhat ahead or lags somewhat behind the e.m.f. waves of the other units in circuit at the same time. This fact that the e.m.f. wave of one generator is ahead or lags behind the e.m.f. wave of the other generators in circuit at the same time is largely responsible for circulating currents. So long as the various generators are three-phase and are connected together on the outside terminals only it is impossible for triple harmonics or multiples thereof to constitute any part of the currents which circulate between the various units. This is on account of the fact that in the outside terminals of no three-phase generator is it possible for triple harmonic e.m.fs. to appear. As soon, however, as the neutrals of the various generators are interconnected the triple harmonic current can flow and under some conditions this triple harmonic current becomes a very large proportion of the total circulating current that appears between the various units. The flow of this triple harmonic current can be readily determined by placing a meter in the neutral connection between the various units in parallel. It should be borne in mind, however, that the current circulating through the windings of the generator is only one-third of the current which is thus measured as coming from the neutral of the generator. The triple harmonic current in each of the three phases of the generator windings are all in phase and thus the triple harmonic current in the neutral is three times that in the generator winding itself. For instance a triple harmonic of 75 per cent of full load measured in the neutral wire means that only 25 per cent of full load current is circulating through the generator windings. The heating effect of such a 25 per cent triple harmonic superposed upon full load fundamental current would increase the total effect only by 3 per cent. It is quite easy therefore to obtain from measurements made in the neutrals of three-phase generators in parallel an exaggerated idea of the importance of circulating triple harmonic current that may be found between these various units. I do not know of any case where so much as 75 per cent of full load current has been found as a normal condition but I cite an example having an excessive triple harmonic current so as to show how unimportant a part such a circulating current really plays so far as heating of the armature winding is concerned.

Another condition has a very important effect upon this circulating current and that is the amount of armature reaction.

In general the greater the armature reaction (that is the poorer a given machine regulates) the less will be the circulating currents which will be caused by a given departure of the prime mover from uniform rotation. The generators of the Interborough Rapid Transit Company, with which Mr. Rhodes is familiar, have very close regulation. Their short-circuit ratio is over three. In other words, this simply means that a given amount of armature current has less influence over the field than the same amount of armature current would have in a generator whose short circuit ratio is, say, two. Conclusions, therefore, which are reached from a study of machines whose short-circuit ratio is three or more, such as the Interborough machines, do not necessarily hold when the short-circuit ratio is considerably less as is the usual practice in more modern machines.

With recent type machines there may be even a considerable departure from uniform rotation in the prime movers and still the circulating current with interconnected neutrals will not reach a value sufficient to cause the slightest inconvenience. A case in point is the experience of a lighting company in Pittsburg. This company operates a number of 4000-volt generators in parallel with neutrals solidly interconnected. The voltage from the neutral to each outside is about 2200 and all of the lighting by this company is done from neutral to outside. These particular machines are driven by gas engines and the plant has been in operation for a number of years. It is well known that the gas engine has about as great a departure from uniform rotation as any prime mover, but in the case cited above there has not been the slightest disturbance of any kind and neither has there been any question concerning the desirability or advisability of operating their machines in this manner. Quite a number of other plants are using the four-wire, three-phase system of distribution and are connecting the neutrals of their generators direct to the neutral of their systems. This method of operation is becoming more and more favored as time goes on and so far as ordinary generator design is concerned there is nothing to prevent it. This has been proven by the experience of quite a large number of plants.

It is quite evident therefore that experience has proven quite the contrary of the broad conclusions laid down in Mr. Rhodes' paper. It is both unnecessary and inadvisable to follow out the suggestion of making more or less freak generators such as Mr. Rhodes suggests for the overcoming of a difficulty which in actual practice does not exist.

G. I. Rhodes: I believe I have answered most of the questions that have been asked of me, so I will say a few words with respect to Mr. Lincoln's remarks. I also know of a plant of large size operating with neutrals solidly connected together, that did not have any trouble. Some months ago an attempt was made to get a manufacturing company to build generators which it would guarantee as to operation with the neutrals in parallel. No such guarantee could be obtained. It is hard to say why there

has been no trouble with the plants Mr. Lincoln mentioned, but if I knew more about the details of the machines, I might be able to explain it.

In response to what Mr. Cory has said about telephone lines, I might bring up an instance of some difficulties experienced with triple frequency current. I have in mind some special tests we made on one of our small turbines, and during this test we had occasion to put in circuit some 35 miles of underground cable operating at 11,000 volts between phases. There was a triple-frequency component of 500 volts in the potential to ground. The neutral current was considerably larger than the line current. The oscillograph record taken during that test was published by Mr. H. G. Stott two years ago. TRANSACTIONS A. I. E. E., Vol. XXVII Part II, page 1536.

C. A. Adams (by letter): As this subject is one in which the writer is greatly interested, he cannot refrain from expressing his admiration for the author's courage in attacking and skill in carrying out even a roughly quantitative solution of this problem. The approximations are necessarily rather gross, but the results should be, and in fact seem to be, close enough to be of great practical value.

There is much food for thought and discussion in connection with the method of analysis and the approximations involved, but as most readers of the TRANSACTIONS are more interested in the remedies for the difficulty, I will stop here to question only one of the author's assumptions, namely that the effective third harmonic reactance at the instant of short circuit " is not over 20 per cent of the (third harmonic) leakage reactance ", if the slot leakage were entirely neglected the coil end leakage alone would ordinarily amount to more than 20 per cent of the total, especially in a 25-cycle turbo-alternator.

Coming now to the remedies, the author has neglected entirely the consideration of fractional pitch windings,[1] although his suggestion of a 120 degree belt span is in some respects equivalent to a two-thirds pitch. A two-thirds pitch with a 60 degree belt would eliminate the third harmonic entirely under all conditions of load, and would save considerable copper and overall length of machine, as compared with the 120 degree belt at full pitch.

Other things being equal the two-thirds pitch winding would require about 15 per cent more slot copper, but a little less coil end copper than the full pitch winding; but as the coil end copper at full pitch is frequently more than 50 per cent of the total, the increase in total armature copper would be only 6 or 7 per cent, which could be neutralized by a slight increase in peripheral velocity. The saving as compared with the 120 degree belt full pitch winding would be 8 or 9 per cent.

It should be noted that the reducing effect of the two-thirds pitch upon other than the triple harmonics is the same as upon the

1. " E.m.f. Wave Shape in Alternators ", TRANSACTIONS A.I.E.E., Vol. 28 (1909) p. 802; " Fractional Pitch Winding for Induction Motors ", TRANSACTIONS A.I.E.E., Vol. 26 (1907), p. 1485.

fundamental, so that the relative magnitudes of these other harmonics remain the same. But the belt differential factor reduces each of these, say the nth harmonic, to 1-nth of its value in the flux distribution curve. Thus with any reasonable shaping of the pole face, the 5th, 7th, 11th, 13th, etc., harmonics will be reduced to comparatively small values. However, if it were important to reduce them still farther, it could be done by a double winding in two layers connected in series, each of the two layers giving the same e.m.f. wave-shape as the original winding and the two layers displaced in phase enough to largely eliminate the more important harmonics. The best phase displacement for this purpose is 30 degrees in a three phase machine, see Fig. 9 of the writer's article on "Alternator Wave Shape" referred to above.

This last suggestion would involve considerable additional insulation and complication in winding, and should not be necessary with any reasonably good flux distribution curve.

The author's second suggestion for a remedy, namely a uniform gap and distributed field winding, seems to be quite feasible, although it would be better when combined with a moderate pitch reduction. It should not be difficult with distributed field windings, such as now in considerable use, to obtain a flux distribution of trapezoidal form in which the third harmonic is negligibly small, but with a moderate fifth harmonic. The latter could then be eliminated from the e.m.f. by a coil pitch of 80 per cent or thereabouts.

S. B. Charters Jr., W. A. Hillebrand (by letter): It may be of interest to know that the phenomena described by Mr. Rhodes can be duplicated under laboratory conditions.

Two identical $7\frac{1}{2}$-kw., three-phase, Y-connected alternators, 380 volts per phase, were operated in parallel on a non-inductive load, with the following results:

Line E.	Load I.	Current delivered by one alternator.		Neutral current.	Neutral Potential.
		Neutral, out or open.	Neutral, in or closed.		
Load... 349.	5.4	3.15	3.35	2.7	2.1
No load 379.	0	3.75	4.1	4.1	3.1

Excitation was adjusted for minimum cross currents between the two machines.

Armature impedance for each leg of the Y-connection, 2.6 ohms at 60 cycles.

$$3 \times 2.6 = 7.8 \text{ ohms, at 180 cycles.}$$

Synchronous reactance per phase of each alternator, 3.5 ohms.

Assuming a synchronous reactance to the third harmonic of 2/9 that to the fundamental, as given by Mr. Rhodes, the neutral current for each of the above cases is computed as follows,

dividing the measured neutral potential by the impedance of two phases in series.
Load

$$I_n = 3\times \frac{2.1}{2\times 7.8+2\times 2/9\times 3.5} = 0.367 \text{ amp.}$$

No load

$$I_n = 3\times \frac{3.1}{2\times 7.8+2\times 2/9\times 3.5} = 0.542$$

Ratio, observed to computed neutral currents,

Load $$\frac{2.7}{0.367} = 7.36$$

No load $$\frac{4.1}{0.542} = 7.57$$

The discrepancy between observed and computed values for the neutral current seems to be due to an amplification of the third harmonic e.m.f. introduced by the third harmonic itself. This was checked by measuring the circulating current in one of the machines operating no load, delta connected, as follows:

Line E	3d Harmonic E with delta open.	3d Harmonic circulating current.
220	17.8	5.0

By computation the third harmonic should be

$$I_3 = \frac{17.8}{3\times 7.8+3\times 2/9\times 3.5} = 0.693$$

Ratio of observed to computed current,

$$\frac{5}{0.693} = 7.22$$

This is a reasonable agreement with the previous ratios 7.36 and 7.57.

The oscillograph showed that the current circulating in the delta was practically a pure third harmonic.

G. I. Rhodes: The apparent discrepancy between calculated and observed neutral currents as given by Messrs. Charters and Hillebrand may possibly be explained as follows: The value

of the reactance to triple harmonic current is given in the paper as the sum of three times the leakage reactance plus 2/9 of the reaction reactance. This latter quantity is defined as the difference between the synchronous and the leakage reactances. The figure given for leakage reactance is abnormally high and on that account is open to some question. It is probable that there was a misunderstanding as to the definitions of the reactances to be used in calculating neutral current.

Mr. Lincoln's adverse criticism of the paper deserves attention. His chief objection appears to be based solely on the wording of the conclusion, without any reference to the subject matter leading up to it. His discussion seeks to establish the fact that alternators as usually designed and built are suitable for operation with interconnected neutrals, without special consideration to design.

The fact that some machines have proved incapable of operation with paralleled neutrals indicates beyond a doubt that design has a great deal to do with it, and the cause of this trouble should be investigated rigidly so that it may be avoided in future installations. This paper has investigated the cause and suggested a remedy.

Mr. Lincoln offers in support of his criticism, the satisfactory operation of certain plants with solidly interconnected neutrals. He gives absolutely no details to indicate whether or not these generators embodied any elements of design tending to reduce neutral currents, or as to their size, number, or conditions of operation. He specifically mentions the generators which have caused trouble, as special, on account of their low armature reaction.

The writer has investigated the only plant mentioned with sufficient detail to afford identification. This plant consists of two 200-kw. 4000-volt, three-phase, Y-connected, gas-engine-driven generators. They are designed with large armature reaction and large leakage reactance, to limit interchange of current. The neutrals are solidly connected together as are also the lines as far as automatic switches are concerned.

What is satisfactory operation?

At the time the writer was in the plant there were occasional surges between the generators sufficient to cause the wattmeter on one to fall to zero, and that on the other to rise to double the load with violent oscillations. The engineers seemed not in the least worried. It was evidently not an uncommon occurrence. Such conditions which were "satisfactory" in this 400-kw. plant would have been disastrous in a plant of 40,000 kw.

This small plant consisted of but two units. It has been found quite possible to operate two units in the plants with which the writer is connected. It was sometimes possible to operate even three, but it was absolutely impossible to operate more than this number. If this gas-engine plant had consisted of eight to ten units as is frequently the case in larger systems, it is probable that there would have been trouble.

Mr. Lincoln makes a statement as to the unimportance of the heating effect of the neutral current. He states that a 75 per cent current corresponds to a 25 per cent triple harmonic coil current. He states the increased heating effect is 3 per cent. This figure should be 6 per cent, for the increased loss is proportional to the square of the current value of non-fundamental frequency. Thus, the heating with 75 per cent neutral current is $1.00^2 + 0.25^2 = 1.063$. The extreme figure given by Mr. Lincoln for neutral current is very much too small. The writer has knowledge of a case in which the current was several times full load. It is thus evident that the heating effect of neutral current is not always negligible.

Mr. Lincoln's reference to the low armature reaction of the machines which have proved incapable of satisfactory operation with interconnected neutrals indicates his belief that this low reaction was responsible for the trouble.

If he had studied the paper instead of the conclusion he would have observed the following:

1. Neutral potential is directly proportional to armature reaction.
2. Neutral current is independent of armature reaction.
3. Neutral current is in the inverse ratio to leakage reactance.

That is, the small reaction had nothing whatever to do with the interchange of neutral current which proved dangerous.

Mr. Lincoln, after attempting to demonstrate the non-existence of a condition proved in the paper without pointing out a flaw affecting the value of the work, criticises the proposed remedies as "freak." That is, a winding occupying 120 consecutive electrical degrees per phase or a smooth rotor with distributed field winding is a "freak." Every two-thirds pitch winding having a belt span of 60 degrees fulfills the first specification. This type of winding is by no means rare, as may be discovered by an inspection of some of the armatures in the shops of the large manufactuing companies. It is frequently used to obtain the best copper economy under certain conditions of design. It is by no means improbable that some of Mr. Lincoln's satisfactory generators which have given no cause for complaint contain such windings, although those examined by the writer had full pitch coils. Many turbo-alternators are now built with uniform air gaps and field windings distributed to give a good wave form. It is safe to say that there are in existence alternators in which the triple harmonic potentials or currents generated are of very small value. They have never before been branded as "freak."

The conclusion given in the paper still stands. It is unsafe to depend on satisfactory operation of alternators with interconnected neutrals unless triple harmonics are eliminated by proper design. Such machines are entirely practicable and should be specified whenever paralleling of the neutrals is required.

Discussion on "American Telegraph Engineering—Notes on History and Practice." Jefferson, N. H., June 29, 1910. (See Proceedings for July, 1910.)

(Subject to final revision for the Transactions).

W. Maver Jr.: I should like to say that this resume is not by any means a full account of the history of American Telegraph Engineering. For instance, in the paper nothing whatever is said about lightning arresters, the forerunners of the switches of which we heard so much this morning. The early telegraph engineers had their troubles with lightning, and the methods adopted to overcome these troubles were numerous; finally coming to the method which is in universal operation to-day, that is, the short path to earth for the lightning current.

About twenty-five or thirty years ago the electric light was inaugurated, following which very quickly telegraph companies began to be troubled a good deal with crosses between the wires of the two systems, with the result that the telegraph switchboards were often burned out, and not the switchboards only, but the buildings of the telegraph companies also. To obviate these troubles as much as possible, the method was employed of coiling up fine German silver wire into coils the size of a pencil, consisting of ten or fifteen turns termed the spider wire. This was put in series with these telegraph circuits at the switchboard, in addition to the short air gap arrester. I do not think the engineers had any thought at the time that the coiling of the wire would have any effect in retarding the progress of the oscillating current towards the instruments.

Ralph W. Pope: The introduction of the Morse telegraph system was followed by what purported to be improvements, and many of these improvements have practically passed out of existence. I refer more especially to the House and Hughes, and the "combination" printers, which followed, leading off with the House printer in 1847 and 1848. I was familiar with the work of that printing instrument, although I did not operate it. My printing telegraph work was confined to the Hughes printer, which was introduced, as you may say, experimentally in 1858, although it did not come into general service. The "combination" printer, so-called from the combining of certain features of the House and Hughes printers by the late George M. Phelps, was, however, used on important circuits by the American Telegraph Company a little later.

One of the defects of the House printer, which was an ingenious machine, was the limited distance over which it would operate, and I would call the attention of the author of the paper presented to the possibility of an error in regard to this having been operated on lines 1,000 miles in length. While that might be true, in a sense, as a matter of fact it was not usually operated between New York and Boston a distance of perhaps 225 miles, except in very fine weather. The ordinary practice was to repeat at Springfield, which was about half way.

One of the difficulties of the early printers in regard to their general adoption was their failure to meet the requirements for way-station work. This was met in the case of the House printer, as is not generally known, by the use of a simplified form of the printer. As the type wheel stopped, the exposed letters could be followed by an expert operator without the use of the printing device. A simpler form was introduced which operated as a dial printer, the operator reading from the wheel, instead of the printing mechanism being used to print on the tape. That was one of the reasons why these earlier types of printers were not successful commercially, for the reason that they could not be used in many stations on account of the expensive equipment.

The question of high speed and the use of the chemical telegraph created considerable interest in telegraph circles at the stage referred to by the author. It is interesting to note that in one of the important experiments made, which is referred to in this paper, that the time consumed in perforating, in transmitting and translating, was more than would have been required by four Morse operators in transmitting the President's message referred to, a difference between seventy-two minutes as against fifty-two minutes. The use of the chemical system raised so many objections that it is not strange it went out of use, but it was at one time quite successfully established in New England, but not using the perforated tape, simply hand transmission, the same as with the Morse system.

The improvements in the Morse telegraph have been largely due to the increased skill of the operators. The use of the typewriter, which has been referred to, brings to mind a rather peculiar relation between the rapidity of transmission by hand and the rapidity with which the operator could receive the same message with a pen. They kept hand and hand, or rather neck and neck, for years, until by the introduction of the typewriter, the receiving operator could copy much faster than the sending operator could send by hand, and this has led to the use of a code for press dispatches, which standardized abbreviations, but the use of the code is not permissible in ordinary private messages, and for this reason the typewriter is still ahead. When we consider the adoption of the mecograph, as it is called here, by the Morse operator for improving the rapidity of his sending, it appears quite possible that the introduction of the Continental code may be brought about some day, as it would require less time, perhaps, to learn to operate by the Continental code used in the wireless system, than it does to learn to operate by these mechanical devices.

The improvements in insulation to my mind have not been so great as the improvements in the conductivity of the line. The early lines, as I recall, used No. 8 iron wire, and then No. 9, and with the introduction of the duplex and quadruplex, as referred to by the author, wires of greater conductivity were

introduced. The form of glass insulator now used has persisted for about thirty or forty years.

The possibility of the utilization of a more rapid system, with the introduction of the night lettergram practice, appears to be quite possible. I have talked with some of the telegraph men about that, but they do not see any probability of it yet. It must, however, take the form, in order to be practicable, of some system of perforation like the Barclay printer which transmits with only one repetition, that is, the perforation producing at the other end a page printed telegraph blank. It is rather remarkable that, although the objections to the form of printing tape were so well known in the early days, there appears to have been no attempt to bring about the introduction of a page printing system. When we consider the ingenuity of those early inventors, House and Hughes, it seems to-day as though, if their attention had been directed to this defect, that they might have invented a page printer, and thus perhaps prolonged the life of the printing telegraph system, which has practically gone out of use.

John B. Taylor: I was a little late in getting in, and possibly Mr. Maver in his opening remarks may have covered one of the points I wish to raise, and that is, that this matter of delivering a telegraph message from a person in one part of the country to a person in another part of the country is something more than getting a code of signals through a given area. It involves a matter of readiness to serve at all hours of the day and night, frequently in small places only during certain hours of the day, and also a system of collecting and delivering messages, assuming that the office is open. This, as far as I can see, is the main reason why these automatic systems, which can send signals over the wire at a phenomenal rate of speed, sufficient to give a thousand or more words per minute, have not gone into anything like general use, and in fact they have gone into use only in very limited cases. Mr. Maver can, I hope, enlarge on this point a little more than I can, but we all of us here see frequently the statement that the telegraph people are not alive to the possibilities of sending messages at a great rate of speed over a single wire, and while a number of messages over a single wire is a good thing, perhaps, between two large cities, it is of practically no use at all to the small towns, of which there are a great many in this country.

The telegraph line is rather apart from the work of most of the members of the Institute, I think, but I am glad that we have had another paper giving an up-to-date resume of the present practice. It is difficult for a man out of the field to know just what is being done. We get hold of the old books and find descriptions of duplex systems, quadruple systems, repeater systems, etc., but as a rule that is not interesting, and if a member of the Institute is interested in this subject, he is interested in knowing what is at the present time improved practice in the

majority of cases, and for this reason I think it is very well that the matter is summed up in this way and spread on the Institute records at this time.

My own recent interest in telegraph and telephone matters has been due, more or less, because of my interest on the side of the disturbance feature from powerful lines, and one or two points occurred to me as Mr. Maver was abstracting his paper. It is plainly brought out by him that the practice of quadruplexing, which means to get four messages over a single wire at the same time, was not worked to an extent, which, at first sight, it would seem that it should be, and this is due to a number of reasons, possibly divided up between poor insulation, variable weather conditions, etc., and to a large extent due to inductive disturbances—I think only to a small degree from short circuits or low inductive disturbances from circuits of the same class on the same pole line, and this raises the question whether the telegraph companies could not afford to use metallic circuits, in which case the matter of inductive disturbances from their own wires, as well as foreign wires, would be obviated. The matter of insulation would still, perhaps, be troublesome, but I think this could be improved without an investment which would be very great, in comparison with the investment in poles, etc., by merely using a better grade of insulators.

There is also the question of using wires of greater capacity by the combined telephone and telegraph, composite and simplex, etc., according to the special system used. Now, if the demand for the telegraph wires and the demand for the telephone wires comes out in just a certain ratio, we might have metallic circuits between all the important points working as telephone wires and also perhaps a sufficient number to take care of telegraph service, perhaps as grounded lines and metallic lines between two pairs of telephone wires. Incidentally, two pairs of telephone wires would be used to make a third telegraph circuit by the phantom arrangement, and again, there might be some uncertainty as to the most economical division of wires between telephone and telegraph circuits, and that matter would be given attention at that time. However, the curve of demand probably varies to a very great extent during the day, the telegraph business of a certain sort going out in the daytime, probably at the peak of the telephone load—but with the introduction of the night lettergram, at day rate—the wires are probably not very busy for telephone work, at any rate since the night telephone rate has been abolished—and it is to be hoped that the recent active interest of the telephone people in the telegraph companies will give a more economical working of the conductors, so that it may appear that the telegraph systems can be worked out advantageously on the metallic circuit, and thus give us the full benefit of the quadruplex and other multiplex systems.

I did not have time to look the paper over very carefully, and

do not know just what Mr. Maver said about the Rowland system, which in the last few years was written up in an interesting paper by Mr. Potts, I believe, where an octoplex capacity was claimed for it. This system used the tape printing device direct from keyboard to the message delivered at the other end, and if this device has been found to work out in practice, it would seem to have been a good thing, but I have not heard lately that any great extensions have been made with it, and if Mr. Maver can say a word or two as to the general reasons for the apparent inactivity, I should like to hear from him.

Incidentally, I believe my name has perhaps been taken in a way to give me more credit than is due. I find in the paper reference is made to the New York, New Haven and Hartford Railroad Company, and a paper presented by me to the Institute in October, 1909, on "Telegraph and Telephone Systems as Affected by Alternating Current Lines," is referred to at the bottom of the page in connection with this matter. While I was interested in the work on the New York, New Haven and Hartford Railroad, for the Western Union Telegraph Company, and described the scheme in actual use, I cannot claim any particular credit for it, but Mr. Scott of the Westinghouse Company, who is here, can tell you to whom the credit belongs better than I can. This cut with my name under it looks like some drawing in a patent application, but I do not think the write-up of the telegraph should be left in its present form, which would give the impression that the present development on the New York, New Haven and Hartford Railroad is to be credited to me.

Gano Dunn: I heard Mr. Maver say that four-fifths of the operators in this country use the Martin mecograph. Is this really so?

My observation as I travel around the country is that we do not see many of them, although I do not get into the central offices.

I have found them imperfect, probably because of my own lack of skill, but there seemed also to be certain inherent difficulties such as difficulty of adjustment and not enough certainty of action to cause all the dots to go through on a long and variable line.

It is also difficult constantly to change the adjustment of the mecograph to follow the rising and falling inductive and leakage changes that are found on a long and poorly constructed line, with many stations.

The wireless telegraph is introducing a greater than ever conflict between the Continental and American Morse alphabet. I should like to know whether there is any attempt towards a more general introduction of Continental Morse into this country, and if so, what Mr. Maver thinks of its probable success.

William B. Hale: Perhaps a few remarks on the telegraph system of the Republic of Mexico may not be amiss. The system there is an extensive one, considering the comparatively few

large centers of population. The telegraph lines extend to even the smallest towns and villages, because, being a telegraph controlled by the Government, its operation is not based upon the question of profit. The Government is ready and anxious to install a telegraph office in any town which has any need for such service, whether it will pay or not. The idea is to supply reliable telegraph service to the entire people at cost.

The general equipment of the system is practically that of the United States of a few years ago. The Morse manual system, with simplex, duplex and quadruplex operation, is in use; and the lines are mainly constructed with No. 8 galvanized iron wire and a European type of porcelain insulator. Wooden poles are chiefly used, but some of the trunk lines have iron poles. There are a few Hughes printers in service in the Capital for communication between the central office and its branches. In the larger cities of the country duplex and quadruplex instruments are used, and in all other offices the Morse simplex is employed. The American closed-circuit system of operation is in use; also the regular Morse alphabet, with a few changes to adapt it to the Spanish language.

The telegraph is used very extensively in Mexico, not only for business purposes, but for social and personal matters as well. To a very considerable degree the Mexican makes use of the telegram where you would the mail, or a messenger service. He sends telegrams from his place of business to his home, messages of congratulation to friends on their birthdays and telegrams of felicitation on such days as Christmas and New Year's. In the City of Mexico one finds a very convenient form of service for such social messages; we have a card, about the size and shape of your postal card, which can be purchased for five cents, Mexican currency, the equivalent to two and one-half cents in your money. On the front of the card is a space reserved for the address and a number of ruled lines for the message, which must not exceed ten words. These card-telegrams, after being filled out, may be deposited in boxes, similar in appearance to letter-boxes, which are placed at the more important street corners throughout the city, and from which frequent collections are made. The messages thus collected are delivered at the nearest branch office, telegraphed to the office which is within the shortest distance of the person to whom they are addressed, and from there delivered by the regular messengers. This is a prompt and efficient, as well as cheap, means of communication within the limits of the Federal District—in the center of which lies the City of Mexico—and it is very extensively employed for business and social purposes.

The rates for telegraph service in the Republic of Mexico are low. A ten-word telegram may be sent from one end of the country to the other for only one peso, or fifty cents in American currency. The rate for night messages, which are transmitted from 10 o'clock in the evening until midnight, is one-half that of the day rate.

We have been unable to use copper wire for pole lines to any extent, for the reason that it is cut down and stolen by the *peones*—the lower-class natives. Iron wire has so far been employed almost exclusively for the construction of pole lines, but I have suggested the use of a steel core copper-clad wire, which will improve the service and will probably not be stolen, as when cut down it will have very little, if any, value as scrap metal. This copper-clad wire will undoubtedly remain up, and it ought to prove especially valuable in a tropical country like Mexico, where even galvanizing does not protect iron wire from corrosion for any great length of time.

The success of the Federal Telegraph System of Mexico would lead one to favor a government-controlled telegraph. The service is rendered at rates much below those which would be charged by a private corporation; and the dispatch of telegrams is in every respect satisfactory, being prompt, efficient and thoroughly reliable.

G. A. Cellar: The employment of reinforced concrete poles for telegraph purposes has not gained much headway hitherto, in this country. I believe the reason to be principally because of the still comparatively low cost of wooden poles, and the lessened expense of handling the latter as compared with that of handling concrete structures. In Europe, however, reinforced concrete masts are more largely used than in this country. The Deutsche Schleuderrehren-Werke has been making hollow concrete poles by machinery, utilizing centrifugal force, for about five years, and with a great deal of success. The Siegwart company about a year ago completed at its Swiss factory a contract for several thousands of hollow poles, averaging forty feet in height, for power lines, constructed by machinery utilizing centrifugal force. My information is that throughout Western Europe, especially Germany, Switzerland and France, and to perhaps a lesser extent in England, concrete poles are now considerably used in place of timber.

Until the time arrives when a permanent location can be secured for a telegraph line—and a telegraph line of large capacity—it may not pay to build an open line of wires supported by high concrete poles, unless their cost shall but slightly exceed that of wooden poles, for several reasons, among which are; first, possibility that the low voltage signaling systems now in vogue may be forced underground, or somewhere beyond the present up-in-the-air location, by the multiplication of electric transmission lines; and, second, by the discovery of a process through which the elimination of retardation in aerial cables may be effected.

I believe that the increase in price of timber, and the advanced cost of handling concrete poles, will result in a revolution in the heretofore accepted models of pole and wire lines, through which there will be evolved a system of short pole lines of either timber or concrete, where reasonably level ground and policing ar-

rangements permit the maintenance of such lines, and for which proper overhead crossings of highways and private roads encountered can be made without grading up and down from each one. It will not be feasible, however, to use extremely short poles in lines traversing rugged country and especially on railroad lines where the undulations of the surface of the ground are frequent and abrupt and the right of way a succession of deep cuts and high fills. Such lines are better calculated for use on highways where the roadway more nearly follows the form of the ground's surface and the ups and downs are not so abrupt. The objection to the use of the very short poles in the lines above indicated is that the vertical pull on the pins and insulators is certain to loosen the contacts with the supports and foster wire troubles in a degree not comparable with the saving in the lessened cost of the line. There is, however, a very considerable expanse of territory in this country in which the use of the short pole line is certainly feasible and desirable, not only through its lessened cost as compared with a line of high poles, but through its lessened exposure to wind pressure and the lessened strain at the ground line in a short pole as compared with a long pole. I am quite sure that for a comparatively small number of wires, a plan of construction can be evolved which will enable the large utilization of short pole lines with, perhaps, dead ended sections where it is necessary to abruptly raise the line in order to carry the wires over road crossings.

The item set forth in the paper as to the housing of insulators is one which I feel will be beneficial in many storms. No doubt the time will come when the expense incidental to such an installation will be more than warranted by the benefit thus to be derived. However, the driving storms of rain, wet snow and sleet which we experience in our western country preclude the entire protection from such storms by any small roofing protection that I think of at the moment.

Louis M. Potts: The authors make the following statement:

> It has long been recognized by telegraph authorities that an ideal system of telegraphy would be a simple and reliable page printer, capable of transmitting and receiving, say from 500 to 1000 words per minute on circuits of from 200 to 1000 miles in length.

This statement is not in accord with my understanding of the requirements demanded by practical men as far as such statements have been made. While it is possibly desirable in some cases that the ideal printer system should be capable of transmitting from 600 to 1000 words over a circuit yet in the great majority of cases the universal printer system would certainly be used at a very much less capacity than this. I take it that this statement of the authors does not necessarily mean a single mechanism to operate at this speed but apparatus capable of giving this capacity to a circuit. A single printer to operate at such a speed as this would certainly involve com-

plications of construction and adjustment such as to preclude its use on short circuits requiring a speed of not more than 40 to 50 words per minute. I suggest that the ideal printer would not be a single printer capable of transmitting and receiving 300 to 500 words per minute each way, but that it would be a printer mechanism capable of operating at such a speed that the number of telegrams handled by the printer is that number of telegrams which can be economically and efficiently handled by a single operator. In a printing system with automatic transmission this number is determined by the capacity of the receiving operator rather than of the sending operator. Of course how many a single operator can handle depends very largely on the accuracy of the system and the traffic handling methods adopted, but from the present state of development of printing telegraphs it would appear that a printer system, manual or automatic, operating somewhere around 50 to 75 words per minute gives an amount of traffic which can be economically and efficiently handled by a single operator. A manual operator does not require a machine of a speed greater than 50 to 60 words per minute. The average operator could not send faster than this whatever the speed of the machine. In an automatic system a machine speed of 75 words per minute should give a sustained rate of about two telegrams per minute. A receiving operator will be fully occupied with this amount of traffic to care for. The operation of a number of printers of moderate speed on a single wire by some method of multiplex operation appears to meet the conditions imposed by those circuits requiring a high capacity machine better than a single printer of high speed. The use of a moderate speed printer makes possible the construction of a simple, cheap and reliable printer which will be suitable for use on circuits having light traffic. This method of treating the problem results in a universal telegraphic printer, and a variation of the methods of line operation only, to meet the different conditions of traffic.

When a certain rate of transmission is reached on any given circuit, the wire cost is reduced to such a low figure that a further increase of rate is not justified, as the further reduction of wire cost so obtained will be more than offset by the more frequent interruptions and the greater amount of supervision required.

If such a system as the authors suggest, as far as the mechanism is concerned, were in a perfect state of development, I do not believe that it could be successfully operated on the wire plant of to-day on account of the variable electrical state of the wires, the lack of protection against inductive disturbances from foreign sources and a nethod of construction which also lacks protection against the induction between the different wires on the same pole line, which makes impossible the use of extremely high speed telegraph apparatus on more than a few wires, and which materially reduces the efficiency of even the Morse manual system. In order that a printer system operating

at a speed even approaching 600 to 1000 words per minute may come into use it is just as important that the wire plant be perfected as the machine itself.

W. J. Camp: I would say that the Canadian Pacific Railway used white porcelain insulators to a considerable extent in the years 1890 to 1898, but the cost increased so much that we reverted entirely to glass until three years ago. We found that the manufacture of glass insulators in Canada had deteriorated so greatly that the insulators turned out were altogether unsatisfactory, apparently they were not properly annealed, with the result that from a week to two months after being placed on the line they would go to pieces without being caused by any mechanical injury. The price of porcelain insulators had also been so much reduced that for the past three years we have used nothing but white porcelain.

Relative to Wheatstone Automatic operation it may be noted that the British Pacific Cable Board has leased a wire from the Canadian Pacific Railway between Montreal and Vancouver and is now equipping this wire with that system.

The Canadian Pacific Railway method for indicating circuits was adapted from the Japanese system and is by small circles at the ends of straight lines, different markings appearing in these circles as follows:

○ Commercial Simplex.
⦶ Duplex.
⊗ Quad.
● Despatcher Simplex.
⊙ Simplex leased.
Composite, Simplex and Telephone.

I consider a line of 40 poles per mile to be the most satisfactory provided that poles are side guyed varying from every 5th or every 20th poles according to danger from storms, and head guyed every half mile. I do not like increasing the number of poles to more than 40 because, besides costing so much more for construction there is also greater reduction in insulation of the wires.

F. W. Jones: In addition to the historical and descriptive parts of the paper, allusion is made to disadvantages and defects in the construction of lines and in the operation of electrical systems of transmission, and suggestions for their improvement are advanced. Any ideal construction of telegraph lines, and the employment of the most improved and speedy systems for the transmission of telegrams must inevitably be limited in cost to the capital that can be secured therefor, and engineering suggestions of any value must keep within the limits of practicability, which is determined by several considerations, probably better known to the presidents and general managers of telegraph and railroad companies, as those officers are charged with the success and financial results of operation and maintenance,

and are de-facto the engineers who decide all questions involved.

That those officers have been able to attain their ideals in these matters is extremely doubtful.

Capital is discouraged by the enormous difficulties encountered in the upkeep and extension of our American telegraph system, such for instance as securing suitable rights-of-way for trunk lines, with their constant demand for added wires; the frequent attempts in Congress to inaugurate a government system; the unfavorable legislation and taxation of the various states; the encroachment of the use of telephones and wireless telegraphy, not to mention the competition of a splendid mail service, besides the increasing cost of labor and materials, and the rigid account to which the proprietors are held by the Courts, for errors and delays which are practically impossible to avoid. Up to the present time the Morse Telegraph system has withstood the inroads of telephone and mail competition, and continues to be favored with an increasing patronage.

The grave situations in which both proprietors and public are placed by the present inability to obviate interruptions to operation between commercial cities, by reason of breakdown of wires and poles, due to storms, fires, floods, snow avalanches falling trees, etc., besides the detrimental effects of electromagnetic and electrostatic induction upon the signals, are not confined to any one company, and their free discussion seems to be well within the purview of the Institute and cannot reasonably be considered gratuitous by telegraph proprietors. In my opinion there are insurmountable financial and engineering obstacles to placing entirely underground the trunk lines between all of the widely separated cities of this continent, except that emergency underground cables may be found an advantage for short distances such as between New York and Philadelphia (90 miles), yet an overhead structure that would be more elastic, built under rigid engineering rules as to strength, number of supports per mile, gauge and number of wires or cables, etc., with reference to the character of the country traversed, and the maximum stresses, (short of cyclones), to which such structure would probably be exposed, could undoubtedly be built at less cost than an adequate and reliable underground system. Upon engineers will devolve the solution of very important questions such as the proper tensile strength of the wires; their ohmic resistance; character of the insulation; and whether open individual wires, or cables be employed. It is obvious that the suggestions in the valuable paper of Messrs. Maver and McNicol, as to the kind and number of poles per mile, are indefinite. As there are great differences of topography and climate to be encountered, different construction is necessary for lines crossing mountains, prairies, mesas of shifting sand, through canyons subject to cloud bursts, and forests where trees are frequently falling, also along the sea coast indented by rivers and bays, and through the latitude where

sleet storms frequently visit. A heavy trunk line in northern latitudes would require considerably different construction from a light trunk line in the south. The annual reports of telegraph companies show an expenditure of many millions of dollars for the repair and maintenance of pole lines.

It is open to engineers to calculate what would be the saving in electric operation, if the conductivity, and consequent tensile strength, were very largely increased over that of the wires at present employed overland. I believe that an increase of at least 50 per cent in the conductivity of the largest H D copper wires now in use, would much more than compensate for their additional first cost, but of course they must be supported by the ideal structure above referred to.[1] The average life of a pole line is given as 10 years, this may be true of wooden poles, but not of crossarms, insulators, nor wires.

It has generally been the opinion of engineers, that to secure reliable telegraph lines between the Atlantic and Pacific, over the Rocky Mountains in northern latitudes, that it was necessary to have the protection of the railroad tunnels and snow sheds. The recent construction of a portion of an important trunk line over the summit of the Sierra Nevada Mountains, will be watched by engineers with interest.

A very vital question to be decided in erecting an ideal line, is the kind and gauge of wire best suited for both trunk and side or way lines, also whether iron, or aluminum, or other metals or compounds could be advantageously used instead of H. D. copper, in case the cost of the latter became excessively high.

The voltage of signaling currents at present in use, particularly for quadruplex, duplex, printer and fast Morse key operation, is at its maximum limits, on account of the detrimental sparks at the contact points of transmitters and of the heating of bobbins of relays, and of the serious menace to the insulation of office wires and underground and river cables.

The increased speed of signals within the last twenty five years, particularly by the use of mechanical transmitters, and by the rapid electrical impulses required for printing and automatic systems on long circuits of comparatively high resistance, has demanded the highest voltages that could be used in order to actuate the relay armatures with sufficient force and celerity.

The mecograph illustrated in the article has a lever that may be moved by a slight motion, from a central or open position, to the right to transmit dots, and to the left for dashes; and is operated by about 30 per cent fewer motions of the hand than is the case with the Morse key, but the motions of the mecograph being lateral instead of vertical, afford relief to the operators muscles that had grown tired from long use of the Morse key.[2]

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1. *Elec. World & Engineer*, March 29th, 1902, page 557. *Telegraph Age*, Nov. 1, 1903, page 540.
2. *Telegraph Age*, July 16, 1906, page 325.

The Wheatstone automatic system has been employed for several years on the long ocean cables, and on overland wires between London and Persia, and has produced more rapid and reliable signals, increasing the carrying capacity of the cables and wires by obviating the loss of time due to the hesitation of key operators in reading copy, and to other causes. Thus changing the cable transmission of business from *intermittent*, to *continuous*.

Repeaters are placed anywhere from 250 miles to 600 miles apart in circuits having very widely separated terminal stations. Such repeaters have their location determined by the convenient position enroute, of a town or city best suited for the maintenance of operators and machinery and not by the object of securing the best conditions for the electrical operation of the wires. The use of quadruplexes is most seriously curtailed by the false signals produced on the neutral relays when the keys on number two sides of several sets in operation on adjacent wires are simultaneously closed, which frequently occurs, the resultant electrostatic induction is then at a maximum.

It is to be hoped that the "ideal system of telegraph authorities in this country" capable of transmitting and printing from 600 to 1000 words per minute on long wires will not lead any of our bright ambitious young engineers to chase an *ignis fatuus*. I am at a loss to understand why the limit was not placed at at least 5000 words. It is obvious that the time-constant of all known line wires, electromagnets, and their connections, for over 200 miles, when operated by the very highest permissible voltage, would absolutely fail to actuate any page printing mechanism at such a speed; it is just as sensible for railroad engineers to ask for a locomotive and cars to carry passengers from New York to Chicago in one hour's time, upon present tracks.

This ideal system must be required for press or similar service where the message contains several hundreds of words, and is prepared in some way for continuous transmission, on its being placed in the machine at the sending end. It is impossible for me to imagine how individual telegrams of an average of 30 words each can be prepared in any manner to be continuously transmitted over a wire at the rate of 33 messages per minute. At the time of Mr. C. F. Varleys visit, and of the subsequent modification of relay resistances by Madison Buell, comparatively nothing was known in the United States of farads, and henrys. It seems that our engineers were then trying to secure the maximum magnetic pull on relay armatures with a minimum electromotive force, and overlooked the tardy action of the apparatus due to high inductance. The adoption of a standard of 150 ohms for single relays was due to the impossibility of a large telegraph company regulating the resistance to suit each circuit. The late W. W. Smith in patent No. 106,418 in 1870 claimed the multiple connection of a 150-ohm relay to the reduced resistance

of 37½ ohms, he found such relays were not so sluggish in action on a wire equipped with a large number of relays, as were the same number of 150-ohm relays, the improvement was one of better service, and not of decreased cost for current.[3]

Donald McNicol: Mr. Jones questions the likelihood of the development of a printer system capable of transmitting 600 words per mintue over ordinary circuits. That one cannot readily conceive of the probability of such speeds being attained, is probably due to the fact that he confines his speculations regarding mechanical operations and movements, to what it has been possible to accomplish in the past by means of electromagnets.

The KR limitations of circuits (including lines, and windings of instruments) where such circuits are spaced into repeater sections of approximately 500 miles, are in the case of aerial lines, of such consequence, that with ordinary voltages, with lines worked duplex; speeds of 300 words per minute are about as high as is possible where the operations are dependent upon electromagnetic control. There is one printer system in use in Europe for which a speed of 350 words per minute is claimed.

It would be, as Mr. Potts implies, a highly desirable feature of a universal printer telegraph system if its operating capacity were as elastic as is the telegraphic traffic in volume on any given circuit, provided, of course, that its general application to circuits having varying loads at different periods of the day, would permit of economical operation as compared with Morse methods, when the volume of traffic is far below that of the maximum capacity of the machine. Flexibility of operating capacity, with a high maximum rate, would serve to take care of varying loads and of the accumulations of traffic due to temporary loss of wires.

With reference to Mr. Jones remarks dealing with the fate of the engineer's recommendations.

The practical engineer realizes that even in the reconnaisance stage any engineering proposition must be worked out with practicability and economy as factors. Even if for temporary considerations an engineering proposition may not be adopted, it still remains that by virtue of the thought and effort devoted to its development, the proposition will survive as a basis for future undertakings along the same lines. Naturally where the engineer is a traffic economist he has given due thought to the requirement that any proposition he may submit calling for the outlay of comparatively large sums of money for new or for additional equipment, must provide for economical results, or in some manner for enhanced advantages over the methods it is intended to improve, which will insure adequate return on the investment. Although the live engineer is professionally zealous, his conservatism would seem to be well established by

3. *Telegraph Age*, Sept. 1, 1902, page 382. *Telegraph Age*, Oct. 16, 1902, page 438. *Telegraph Age*, Nov. 16, 1902, page 476.

virtue of the fact that the major number of the propositions submitted to him for investigation are found to be and reported as impracticable or unprofitable.

W. Maver Jr.: The President is very desirous of getting to the other matters scheduled for the program this evening, and I shall therefore at present only say a few words in reply to the points brought out in the discussion.

Mr. Pope queries the statement that places the distance of transmission by the House printer at 1,000 miles. The statement is traceable to the officers of the original House telegraph company and may be found in "Electric Telegraph," Jones, 1852, page 112, as follows: "The longest line we have is about 1,000 miles—extending from New York to Cincinnati. Messages are transmitted that distance with ease; and no doubt we shall be able to telegraph direct from New York to St. Louis as soon as our line, now building, is completed." Possibly the discrepancy between this statement and Mr. Pope's experience may be explained by a superior conductivity of the newly constructed wires in 1852 as compared with the wires of Mr. Pope's time. It was the common experience of those days, 1865-1870, that, owing to the manner of making joints then in vogue, (a simple twisting of the ends of the wire without solder), the resistance at the joints in a few years almost amounted to a break in the continuity of the wires. For instance, one of the New York-Bridgeport wires tested by Mr. Varley and mentioned in his report (see page 1289) showed it to have a resistance of 241 ohms per mile—normal resistance 13 ohms per mile.

In regard to early attempts to produce a page printing telegraph it may be noted that Charles Wheatstone, about 1840, devised a page printer telegraph system, but it was rather slow and did not get into general operation. Described Sci. Am., May 31, 1884.

Mr. Taylor expresses the opinion that some of the present trouble on multiple telegraph circuits is due to the mutual induction between parallel wires. About twenty years ago I had a very large experience in the practical operation of multiplex telegraph circuits while I was the electrical engineer of a large telegraph company in this country, and the statements on this point in the paper are based upon that experience—we operated circuits between New York and Boston, five or six quadruplex circuits on parallel wires at top speed, obtaining an efficiency virtually of one hundred per cent, except in very bad weather. I found, that when we already had five or six parallel quadruplex circuits, the imposition of additional circuits did not have any detrimental effect upon the operation of the others. Hence, I feel safe in saying what is said in the paper—if it were possible to get rid of the stretches of underground cable and the inductive disturbances from high tension transmission circuits, it would be possible to restore the former conditions of multiplex operation.

The disuse of the Rowland printer in this country is probably due to a number of causes, chiefly perhaps the somewhat complex nature of the apparatus and its unreliability at times. Mr. Taylor himself suggests some of the causes for the present non-use of high speed chemical automatic systems, to which it is assumed he refers, having the phenomenal speed capacity of 1000 words per minute. Numerous other causes have been cited at times without number by those who have had practical experience with such systems. It is pointed out in the paper that automatic systems capable of transmitting at the high speeds mentioned were in operation in this country 30 years ago and are still freely available when desired.

As to the statement relative to the extent of use of the vibroplex, mecograph, and similar instruments to which Mr. Dunn has referred, namely, that four-fifths of the operators now use such instruments, it may be said that investigation will probably confirm that statement. So far as the feasibility of transmitting speedily with this device is concerned, it can be stated that duplex circuits are being operated now between New York and San Francisco, with, I think, three sets of repeaters, by means of semi-automatic transmitters at the highest speed of manual Morse transmission.

Charles F. Scott: Is that repeating done automatically?

Mr. Maver: Yes, regular automatic repeaters, duplex repeaters. The method is described in the paper. The matter of displacing the spaced letter or American Morse alphabet as used in the United States and Canada, by the Continental Morse Alphabet has been proposed frequently within the past 50 years without result. There is no question that for manual sending the American Morse alphabet is the speedier, there being 214 time units in the American to 214 time units in the Continental, exclusive of numerals, and the liability to errors due to the spaced letters of the American Morse alphabet is minimized by the fact that the operators by habit almost universally exercise extra care in the transmission of words containing spaced letters. In automatic transmission, however, as by the Wheatstone system, the use of spaced letters is a source of delay as it is virtually necessary to double space words containing spaced letters in order to avoid errors. Thus the situation stands at present. Possibly the use of the Continental alphabet by wireless telegraph operators may assist in leading to the general disuse of the spaced letter alphabet.

Exception may be taken to Mr. Jones statement that the presidents and general managers of telegraph and railroad companies are de-facto the engineers who decide all questions involved. They may act adversely or favorably upon the reports of their engineers for financial or other reasons, but that does not constitute them the engineers of the company. Apropos of this may be quoted the following sentences from a recent

paper by Mr. George Westinghouse* "In view of the fact that there had been no considerable demonstration of the single-phase system by actual use, and that the New Haven trains would be obliged to operate upon twelve miles of lines already equipped with the direct-current third-rail system, it must be conceded that the directors and management of the New York, New Haven and Hartford Railroad showed great courage and confidence in the judgment of their experts." Mr. Jones is quite in accord with the authors of the present paper in expressing his opinion that the financial and engineering obstacles to placing entirely underground the trunk telegraph lines between all of the widely separated cities of this continent, etc.

Mr. Jones statement that the resultant electrostatic induction is a maximum when the keys on the No. 2 sides of several adjacent quadruplex sets are simultaneously closed will bear considerable qualification. For instance, there must be a particular coincidence of polarities to line on the No. 2 sides to bring about this maximum. One can easily conceive of a condition of complete neutralization of ill effects, depending on the polarities to line at a given instant, when all the No. 2 keys are closed. Furthermore, instances are cited in the paper in which many adjacent quadruplex sets have been operated without any impairment due to the cause stated.

Concerning Mr. Jones wonderment that the limit of transmission of an ideal printing telegraph system was not placed at 5000 words per minute, instead of 600 words per minute, the reason may be that the authors were desirous of keeping within limits that are at least eight times nearer attainment than Mr. Jones' system. Mr. Jones' arithmetic is perhaps astray in the computation that a transmission rate of 600 words per minute would involve preparing 30 word messages at the rate of 66 messages per minute. Twenty messages per minute is nearer the mark and twenty operators could easily prepare the messages at that rate. Mr. Jones seemingly bases his dictum that the time constant of all known line wires, electromagnets and their connections for over 200 miles would utterly prevent the operation of a printing telegraph system at the rate of 600 words per minute, upon the assumption that present methods must be strictly adhered to. This was not made a condition of an ideal printing telegraph system by the authors. The Buckingham-Barclay printer to-day has a capacity of 100 words per minute in each direction over circuits 1000 miles in length. In transmitting by this system each letter requires an average of nine time units made up of short and long pulsations of current of opposite polarities. The Murray printer of 150 to 180 words per minute employs five time units for the transmission of each letter. For the Creed printer, employing the Wheatstone alphabet, it is claimed that 225 words per minute may be transmitted.

*A paper prepared for the joint meeting of the Am. Soc. M. E. and the Inst. M. E., London, July, 1910.

The Wheatstone automatic telegraph system which employs an electromagnetic ink recorder is capable of transmitting messages over regular telegraph wires at the rate of 600 words per minute, using the continental Morse alphabet, which requires an average of 8 time units per letter; the equivalent of 8 pulsations of minimum duration per letter. It is therefore perhaps not the time constant of the line or apparatus that stands in the way of a 600 word per minute printer so much as the present cumbersome methods of selecting the letter to be printed; together with the more or less cumbersome printing apparatus.

Hence it is conceivable that by the use of a method in which the time units required per letter may be halved or quartered the speed of transmission may be doubled or quadrupled without any change in the line or receiving apparatus, a result that would bring the speed of transmission quite close to if not beyond 600 words per minute. So in this respect as in some others Mr. Jones' railroad analogy is not as apt as at first sight it might appear to be. But the suggestion of an ideal printer telegraph as noted in the paper does not confine the prospective inventor to existing electro-mechanical apparatus. Photography and other physical agents controllable by electrical impulses are open to the ambitious and qualified inventor, who, however, could not say that the context of the paragraph in the paper relating to an ideal telegraph system conveys the impression that the realization of this ideal system is devoid of difficulties.

Mr. Cellar's remark relative to the housing of insulators indicates that he misses the suggestion of the paper that relates to the housing of the wires for mechanical protection against storms. Mr. Cellar's immediately following comment on the destruction of open wires by storms however emphasizes the said suggestion; as does also Mr. Jones mention of the annual expenditure of millions of dollars for the repair and maintenance of pole lines.

With reference to Mr. Pott's remarks concerning the impracticability of operation of high speed printing telegraph systems on wires subjected to severe inductive disturbances, it may be pointed out that a perusal of the paper will show that the authors are in strict accord with Mr. Pott's in this view.

It is noteworthy that many of the important inventions in mechanics and electricity have not been due to men directly engaged in the industrial application of those arts. Watt, for instance, was an astronomical and mathematical instrument maker. Morse was an artist by profession. Stearns, Bell and Pupin were not in the telegraph or telephone service when they produced their notable inventions in telegraphy and telephony respectively. Murray the inventor of the successful printing telegraph that bears his name was a journalist. Creed left the telegraph service to devote his time to the development of his ingenious punching and printing telegraph, and the list might be continued almost indefinitely.

One explanation of this fact may be that in the majority of cases the active engineers in an art are fully occupied with the successful operation of existing apparatus or with problems connected therewith, and are given neither the time nor the financial aid necessary to undertake original research for the advancement and betterment of the art with which they may be associated. Another explanation may be that in many cases the engineers in question are operating engineers, but not inventors. This suggests the question whether men thoroughly familiar with the requirements of telegraphy and of all the conditions to be met with in the technical telegraph service, and largely endowed with the inventive faculty might not be selected to prosecute investigations relative to the improvement of the telegraph service as relates to the transmission of messages, analogously as selected men in the medical and other professions and arts are now exclusively employed in matters relating to the advancement and improvement of those professions and arts.

DISCUSSION ON "TRANSMISSION LINE CROSSINGS OF RAILROAD RIGHTS-OF-WAY" SAN FRANCISCO, CAL., MAY 6, 1910. (SEE PROCEEDINGS FOR JUNE, 1910.)

(Subject to final revision for the Transactions.)

John Harisberger: I would ask Mr. Babcock if he has any suggestions for a satisfactory crossing for the right of way by transmission lines?

A. H. Babcock: The only suggestions are those embodied in these specifications. The first and second paragraphs cover the point, that up to the present no basket or guard, or similar construction has been found satisfactory. The power companies themselves have attempted to develop that sort of thing and have found that after it was put in service there were so many disadvantages, that the device had ultimately to be abandoned. It is thought now that the only satisfactory way of handling the subject is to make the crossing so strong mechanically and electrically that it cannot come down at that point.

John Harisberger: The requirements of the Northern Pacific have been to place poles on either side of the track so high that even if a wire broke it would not reach at most the top of a box car. It seems to me that that would be the requirement if the right of way were not of such width that it would be impractical.

A. M. Hunt: In paragraph 27, "Conductors," Mr. Babcock has stated that "material: copper, aluminum, or other non-corrosive metal," should be used. It would appear to me that the element of strength in the conductor over the track is the main essential, and that perhaps could be better attained by the use of heavy galvanized steel conductors, such as cross the Straits of Carquinez, used by the Bay Counties Power Company. They are steel cables and are always kept painted and in first class condition. The possibility of rupture is very much less than if they were of copper or aluminum, or material of equal conductivity. That one point of exception can well be taken to the specifications.

C. F. Adams: In clause No. 19; "Material: cast steel, malleable iron, or other crude metal, galvanized." Under that specification a cast iron pin could be used. In paragraph 23 it states: "Insulators shall be designed for voltages 25 per cent in excess of the rated working voltage of the other insulators on the line." I believe that if a step of that kind were taken, it would result simply in the taking of a succession of steps. In other words, the general public would call for as good an insulation as the railroad company did, and then the railroad company could call for 25 per cent in excess of what the public were then getting. It seems to me that what is proper for the entire system should be sufficient for the railroad company.

There is one other point that I note here, which does not seem to have been embodied in the presentation of this paper. It states: "In general, it is advisable wherever possible to place

underground all low potential power circuits, and communication circuits." I believe that clause is correct, and I think also that it should be applied to communication circuits of telephone signal and telegraph lines by the railroad companies. I know of nothing better than a few feet of earth and a little lead to protect from a high-tension circuit falling to the ground.

Lewis B. Stillwell: I agree fully with Mr. Babcock that special and adequate protection should be provided in all cases where high-potential transmission circuits cross railway lines. I do not think, however, that the problem is one of any great difficulty. It is to be noted that the accidents mentioned by Mr. Babcock, with one exception, were not occasioned by reason of the fact that the circuits were not properly protected. They were purely mechanical accidents and due to gross carelessness. In Italy, notably on the Valtellina, a wire net is suspended beneath the transmission circuits where highways are crossed. These are somewhat awkward in appearance, but properly erected and maintained, they appear to afford adequate protection. Crossings of this character should be built upon the same principles upon which bridges are constructed, that is to say, they should be built so that the line will not fall down. As a bridge problem, railroad crossing by a transmission circuit is very simple. Ample factors of safety are practicable and a little care will provide against failure. If a circuit breaks between two poles or towers on opposite sides of a railway crossing, provision should be made for grounding that circuit before it can touch the locomotive or car passing beneath it. This can be accomplished by placing a grounded conductor in a horizontal position, where the falling conductor must touch it before reaching the top of the car.

As regards the specifications suggested by Mr. Babcock relative to conductors, it would seem that while this is unobjectionable in general from the standpoint of the power company and should be satisfactory to the railway company, specification No. 27 could be made more definite by requiring in general terms a mechanical factor of safety rather than prescribing arbitrarily the size of the wire with reference to the voltage. It would be reasonable to require that the span crossing the track be constructed with a very high factor of safety. In conjunction with this, some plan of grounding the circuit and cutting it out automatically in case the wire breaks, would be unobjectionable.

I understand that in the judgment of the engineers of the Pacific Gas & Electric Co., automatic circuit breakers are not yet developed to a point where they can be relied upon for very high potentials. This being the case, if the two towers supporting the wires which span the railroad be connected electrically by adequate earthing or by conductors and provision made for effectively grounding the conductor in case it breaks, I do not see how any material damage to a car is liable to occur.

P. M. Downing: There are a few points in the paper which I think might be improved upon slightly, but in general, I think the specifications as proposed, come nearer meeting the approval of the power companies than anything that has yet been submitted. Our experience here on the Coast in the matter of protective devices where power lines cross railroad rights of way, is a rather long one. We started in with the idea of using some sort of a basket device to catch the wires in case they should break at these crossings. These basket devices consisted of wires carrying a sort of lattice work in order to catch the broken circuits, but we found that these baskets were more of a menace than protection, for the reason that they were very hard to maintain on a long span, and where the railroad right of way was wide, the strains thrown on the supporting structure was very great, and we had so much trouble with those that they were finally abandoned.

The specifications, as I understand them after going over them very hurriedly, provide for good mechanical construction. To my mind, this comes nearer meeting all requirements than anything else which could be submitted. However, as I say, there are a few points which, to my mind, might be improved upon, but I have not gone into the specifications fully enough as yet to be entirely familiar with them.

Markham Cheever: To one who has been interested in this subject for a considerable time, the prefatory remarks in the paper appear as a most excellent statement of the present status of the problem. The old basket type construction as pointed out by the author is obviously inadequate and introduces an element of hazard greater than the danger it prevents. Numerous other designs have been proposed, many of them involving a tension in the crossing span less than the tensions either side, and this again introduces additional risk by reason of the many dead-end connections. It is now being widely recognized that a more reliable construction is produced by running each line conductor straight through, avoiding any splices or dead-end connections in the crossing or adjacent spans, and maintaining uniform tensions. A design based upon this principle has been largely used for the crossings of high tension lines over the tracks of the New York Central Railroad. Two towers are placed close to the railroad right of way, one on either side. The precautionary feature consists of auxiliary ties to each line conductor from insulators supported on the track sides of the structures and at lower elevations than the main insulators. Should the conductor break on the supports adjacent to the track or at any point behind, allowing the conductor to slacken, the auxiliary ties hold the crossing span suspended, at the same time efficiently grounding it.

Sidney Sprout: Some gentleman made the remark a few moments ago that a few feet of earth between the transmission

line and the telegraph line was probably the safest insulator that could be had. I have noticed that the telephone company, the Pacific States, at its crossing with street railways is making a general practice of putting a cable underneath the streets. I will offer just a few suggestions, as I have not read the specifications through since I came in. I did not expect to take any part in the discussion, but I think if we would reverse the specifications somewhat, where there is a trolley crossing or a high tension transmission crossing of the railroad, considerable difficulty or danger can be eliminated by the railroad companies putting every 200 feet their telegraph and signal lines underneath the ground in a cable. I believe they do that at present at a number of places along the lines where they enter the depots. This seems to me to be a way to avoid the difficulty that came up in one of the cases mentioned at Antioch, where the towers were built carelessly, or otherwise, and dropped across the line, and that would make, of course, considerable confusion. I think that the transmission companies or the power companies would be perfectly willing to pay for any expense of running underground at such places as they cross. Of course, the other dangers of lines coming down on the track, and the trouble, the mechanical trouble, of engineers, and so forth, would not be avoided by this; but it seems to me that the greater part of the danger of which Mr. Babcock speaks, would be avoided by a very slight expense of running the wires underground. I think that the transmission people have racked their brains and spent considerable money for suitable means of crossing railroad lines, as well as telephone and telegraph lines, by which they might be saved from annoyance or the liability of danger that they are causing by running overhead. As some gentleman has said here, the very means that they expected the most of, seemed to fail; and I believe that if we look on the other side of it, that the telephone people have done it probably unintentionally, or possibly because electric people have delayed in putting in proper protection—and of course they have protected themselves—but it seems to me that they have solved one of the great troubles and annoyances by putting all of their lines underneath the track where they cross street railways or steam railroad lines. I know they still call on transmission people to protect their lines, but I believe they would rather put their lines underground than to run the risk and danger of the wires breaking and coming down on to a trunk line service. A great many of our lines cross the telephone and telegraph lines between the main stations, Los Angeles, San Francisco, and Portland, and it means considerable to them if it does break down. I appreciate the necessity of something being done, and I think that Mr. Babcock's paper is one that we should consider very seriously, and I think that the Institute should take some steps regarding the matter, instead of letting it drop without more serious thought than what has been already brought out.

J. P. Jollyman: Mr. President, I believe that it is possible for the power companies and the railroad companies to reduce their troubles to a minimum. It is undoubtedly possible to construct a protection that would be absolute, but the question of cost would be prohibitive, except in very special cases. The power companies are interested in the matter nearly as much as the railroad companies, and anything that will be to the advantage of the one, would be of advantage to the other. The matter of underground crossings is something that would have to be studied very carefully, for an underground crossing in connection with a telephone, telegraph or signal service line may add to the difficulty, of satisfactory operation. In some cases the companies operating these lines might even prefer to go overhead and take their chances. I think, on the whole, that the specifications as read by Mr. Babcock, if faithfully carried out would lead to as safe a crossing as can be reasonably expected under present conditions.

R. W. Van Norden: I have not read this paper as carefully as I would like, but, from the discussion which has been given so far, I cannot see but that the necessary points are covered as well as they can be, as Mr. Jollyman says, without too much cost. On the section that Mr. Babcock spoke of, on the Southern Pacific, we have built a good many crossings, and while we have used small wire, I do not remember that we have had an accident where it affected a telegraph system, but possibly once, and that was not at a crossing, but was in the case of a blast at Rocklin that threw the transmission line down, and the blast affected the telegraph signal system. I do not recollect that there has ever been any serious break at any crossing. The only system we used was the basket system, which I do not particularly believe in. There have been some experiments made along the lines suggested, of grounding, so that in breaking it grounds before striking earth. Those have not been carried out very carefully, so I cannot tell you what the experiments resulted in.

President Stillwell: I do not fully agree with Mr. Cheever in regard to the basket suspension plan. Its effectiveness is purely a matter of construction and maintenance. In Italy, apparently they maintain it properly—that is what we do not always do very well in this country. We put up devices of this character and then fail to maintain them. In my opinion, the basket construction, while not the best, can be made effective in the case of comparatively short spans, if properly maintained.

R. W. Van Norden: There is another point that I think of. Mr. Hunt spoke of putting up steel in place of copper or aluminum. I know of one case where we used steel in spans, and one of them was across a railroad track. Some of the wire was copper wire, very small No. 6, and I think the span was between 800 and 1000 feet long. We used also No. 6 steel telephone

wire. The telephone wire broke in the winter time a number of times, but the copper wire would not break at the same time, apparently due to snow loads on the line. The steel would pull out, it would not make a quick break, it would pull out to about one-half of its diameter, and then it would break, but the copper would not break at all.

C. F. Adams: I would like to reply to the suggestion of the President concerning the matter of grounding. That would be operative on lines of limited length and low frequency. On lines approximating the length that you will find here in California, with a frequency of 60 cycles, if it is grounded 100 miles from the station, it does not give you enough short circuit current at the station to overload the generator and carry it beyond normal. That has been tried out, and it has been thoroughly demonstrated that a short circuit may occur on any one of the three phases and yet the operating station may not have sufficient indication of a short circuit to really warrant them in pulling their current off the line.

President Stillwell: This sort of a paper is an admirab'e one in my opinion; it is not overloaded with unnecessary explanations; it is precise and explicit, and is a very essential start toward standardizing a very important matter, and I think that at the proper time, the standardizing committee of the Institute operating, for example, in conjunction with the proper committee representing the railways, might agree once and for all upon specifications which would be adhered to. That would save a great deal of trouble to all concerned, and I see no reason why a question of that kind cannot be taken up in that manner.

A. H. Babcock: Mr. Harrisberger suggests that adequate protection can be secured by using high poles set so close to the right of way that a broken wire will not be able to strike the tracks. Doubtless he has in mind narrow rights of way. The Western Railroads often have 400 oot rights of way so that it is difficult to see how poles can be erected high enough to prevent a broken wire striking the signal and telegraph circuits.

As a rule the wires break near the support, either by vibration or by burning.

Mr. Hunt mentions the possible use of iron wire or steel wire under section 27 of specifications, and cites the case of the Carquinez Straits span where the cable has been operating for a great many years with great success. I think he overlooks the point that the Carquinez cable is so heavy that a man can be sent out on the cable to inspect it and to maintain it. In certain sections of this country the salt fog will eat up an iron wire in a very short time. Experiments made along the east side of San Francisco bay show that the ordinary galvanizing of overhead trolley line parts is by no means an adequate protection, and that the metal rusts very quickly. For these reasons it is doubtful that any small iron wire, say No. 4 or

No. 6, can be used to make a thoroughly safe construction, without a great deal of maintenance cost in the way of replacements. Usually a transmission line wire is put up and forgotten as long as possible, so that the railroad company has reason to be suspicious of iron wire crossings.

If I understand Mr. Adams correctly he feels that the iron pipe pin would be barred out by section 19. Possibly it might be well to make an amendment there and mention specifically iron pipe.

The President has referred to the protection used on one of the Italian lines with which I am not familiar. Some of the French lines use a through span bridge over the tracks, through which both the telephone and transmission wires are carried. It is difficult to imagine a more complete protection than is afforded by such construction, but it is very expensive. It is neither equitable nor possible to attempt to shift the total burden of the expense of such crossings entirely from one party to the other. It is properly a matter of joint responsibility and interest. The broad principle involved in this matter is met by the railroad man every day in the crossings of his rights of way with other railroad rights of way. The senior road at the crossing does not stand much of the cost, while the junior road bears the greater part of it. A road that is senior in one place may be the junior road in some other locality because lines are being extended all over the country. We have a number of such cases—for instance, in connection with the power transmission lines now operating in this part of the country. In these cases undoubtedly the railroad company will be obliged to stand the greater part of the expense.

The foregoing remarks will refer also to Mr. Sprout's and Mr. Jollyman's discussions.

The suggestions made by the president that the railroad companies and the Institute shall join in a general discussion of this subject seems to me to be one that may have a very far-reaching consequence. I, for one, would be very glad to see such an arrangement brought about.

Ralph D. Mershon (by letter) Mr. Babcock's paper deals with a subject to which I have given considerable attention. Some time ago I wrote an article dealing with the subject.* It embodied my ideas as finally crystallized after various discussions and investigations relating to the subject. The endeavor was made to lay down the conditions which should be met in transmission line crossings in order to ensure safety. I quote these conditions, from the article, as follows:

(*a*) It should be so constructed that the line conductors (line wires or cables) and the supporting structures at each side of the track would be of proper strength to withstand the

*"Transmission Line Crossings over Railroads", *Railroad Gazette*, February 7, 1908.

ice and wind loads which might come upon them. It should be self-sustaining; that is, should be capable of standing up under the action of wind and ice without reference to the remainder of the line, so that the line on one or both sides of the crossing, might break without interfering with the crossing itself.

(*b*) There should be sufficient overhead clearance between the line and the track, so that there would be no possibility of contact except by deliberate intent.

(*c*) The line conductors should be far enough apart so that they could not swing together.

(*d*) The line conductors should be sufficiently massive so that an arc might exist between them for several seconds, without danger of burning or melting them off.

(*e*) If the supporting structures are of steel, or the insulator pins are of metal and the pins connected to each other, or to ground, the insulators should have cast metal caps cemented upon them. These caps, or extensions of them, should extend out on each side of the insulator for some distance along and underneath the conductor, in order to further protect the conductor, or else the conductors should have, in addition to the caps, a protection from arcs in the form of a serving of wire upon them for some distance on each side of the insulator. The result of such protection will be that an arc formed near the insulator will expend itself upon the serving wire, or metal casting, instead of upon the conductor itself.

Mr. Babcock has gone into this matter in greater detail than was attempted in the article above referred to. In general, his specifications appear to me to conform with the ideas as laid down therein, though they do not seem to me as clear as they might be in regard to the matter covered by the latter part of (*a*). Apparently his specifications are intended to cover the construction of the supports and cables not only of the crossing span but of the adjacent spans on each side of the crossing span, and they contemplate the construction of these three spans of equal strength. Yet in item 17 he specifies the strength of the steel structures for the crossing span only, and says nothing about the supports for the two adjacent spans. It seems to me that, in general, it were better to so design the three spans that those adjacent to the crossing span could go down without injuring the crossing span. I will deal with this matter further in my remarks under ¶ 27.

There are a number of additional minor points in Mr. Babcock's specifications with which I do not quite agree. These differences will appear from what follows, in which I shall refer to such of the items of the paper as seem to me should be modified, designating them by the figures used in the paper.

¶6. This item contemplates that the power wires shall necessarily pass *over* the wires already on the right-of-way. It seems to me that there might often be cases where it would

be safer and better to have the power wires pass *under* the existing wires, the latter crossing the power wires with a span so short on structures so high that, even though the existing wires should break near one structure, they could not reach the power wires.

¶20. It seems to me that not only should the pins be electrically connected to each other, but that this connection should be effectively grounded, especially if the wooden cross-arm is carried by a wooden structure. In the case of a metal cross-arm carried by a wooden structure, the metal crossarm should be grounded.

¶25. In the present state of the art of making the inter-connective link type of insulator, it may be working a considerable hardship upon the power transmission companies to require their use. And, so far as my experience goes, the cemented form of suspension insulator can be safely depended upon.

¶26. I am not quite sure that I understand this item, but if I do it seems to me the clearance provided is rather small. For 100,000 volts, for instance, it would be only 19.6 in.

¶27. I do not quite see the reason for making the minimum size of conductor less with lower voltages than with higher ones. Other things being equal, the danger of burning a conductor is greater with a lower voltage than with a higher one. Because with the same power capacity in each case the arc with the lower voltage would be heavier than with the higher. Inasmuch as the power capacity of the circuit as well as the voltage has to do with the amount of damage that might be done by an arc, it would seem to me better to either specify the size of the conductor with reference to both the power and voltage, or else to specify for all cases a conductor so heavy as to take care of any condition which might be met with in ordinary practice. It seems evident from this item and the next one that Mr. Babcock contemplates that the same size of conductor shall be used upon the crossing span, and the two spans on each side thereof. I should suggest the consideration of a great deal smaller and weaker conductor on each of the adjacent spans, so that if the transmission line itself should go down the conductors of these spans might break before injuring the crossing span.

¶32. I am not sure what this paragraph means. If it refers to the use of the device consisting of an auxiliary insulator and a connection from it to the line cable, together with a grounded guard against which the line cable is supposed to land in case it is burned off, the advisability of such provision seems to me questionable. I should prefer to make the cables heavy enough, and so protect them near the insulators, that they would be capable of successfully withstanding a power arc until the circuit breakers controlling the power line opened, or until the arc ruptured itself, in case the circuit breakers failed.

¶35. I do not see why the horizontal wind pressure should be added to the weight of the conductor and its covering of ice, instead of taking the resultant of the weight and wind pressure. I presume, that this wording of this item is an inadvertence.

Frank F. Fowle (by letter): The paper by Mr. Babcock agrees very well in its general recommendations with the conclusions presented by the writer two years ago in a paper prepared for the Association of Railway Telegraph Superintendents, and since published. The writer also attacked the fallacy of screen and basketwork protection some four years ago, which Mr. Babcock aptly characterizes as an engineering anomaly.

In general the problem presented is that of designing a transmission line crossing so that it shall be stronger electrically and mechanically than the balance of the line, and so that the probability of failure shall be practically extinguished. The crossing should compare with the balance of the line as follows:

1. The mechanical and electrical factors of safety should be greater.
2. The conductors should have greater conductivity per unit of length.
3. The conductor separations should be greater.
4. The entire structure should be absolutely fire proof for voltages above 10,000.
5. The protection against arcing should be greater, and against the effects of arcing.

A factor of safety in mechanical stresses of 3 is often recommended for dead loads, but in view of the possibly great damage that would result from failure, a factor of 4 seems to me no more than adequate. In choosing a factor of safety, the elastic limit as well as the ultimate strength should be considered.

For voltages below 10,000 where steel structures are for any reason not possible, the cross-arms and pins should be of steel in any case. Single wooden poles are not desirable, and some form of fixture made of two or more poles, such as an "*A*" fixture, or an "*H*" fixture, seems very essential. Wooden poles should be fire-proofed for several feet above the ground, and the butts should be creosoted. A factor of safety of 6 is recommended for all timber. Steel cross-arms and pins on timber structures should be thoroughly grounded.

Insulators designed for electrical stresses 25 per cent in excess of the main line would seem to be no more than adequate, especially in view of the fact that the damage done by lightning, and the maximum stresses caused by it, are largely local. A larger margin of safety in the insulators appears to be desirable in districts where lightning is severe.

As regards conductors, the unreliability of single aluminum strands of small size prevents their use; and aluminum should always be stranded. No. 6 B. & S. copper has an ultimate strength of nearly 1,300 lb., and is hardly suitable for crossings

of this character. A minimum size of No. 2 B. & S. or No. 0 B. & S., stranded, will be better practice. If this size of copper has more than the necessary conductivity, copper-clad steel of corresponding strength may be substituted. The conductivity and diameter of conductor at the crossing should exceed that in the main line by at least 25 per cent.

Low-tension circuits carried on the high-tension line should be treated at the crossing as though they were high-tension circuits, for a failure on the line at some distance from the crossing may impress a very high tension on these circuits for a short time, causing them to break down at numerous places. If this proves to be a more costly procedure than carrying them underground at the crossing, the latter course is the obvious one.

Sleet loads vary greatly in different parts of the country, according to climate. A radial thickness of $\frac{1}{4}$ inch may suffice in California or in the extreme South, but it is much too small in the Central and Eastern states. The writer has seen accumulations on small wires in Illinois of about 1 inch radius, in severe storms. The records of the Weather Bureau will frequently furnish the necessary data upon which to base safe practice in this respect.

A wind pressure of 20 lb. per sq. in. on flat surfaces normal to the wind, computed from the formula,

$$p = 0.004 \ V^2 \tag{1}$$

corresponds to a velocity of 70.7 miles per hour. The writer found that for a period of ten years, at Chicago, the highest recorded velocity during a severe sleet storm was 50 miles per hour. The Weather Bureau maxima are based on observations at 5-minute intervals with a cup anemometer. Observations made with the Dynes pressure anemometer show instantaneous velocities, as much as one-third in excess of the 5-minute maxima of the cup anemometer, uncorrected. This indicates instantaneous true maxima as high as 67 miles per hour.

The Chicago observatory is 310 ft. above the street level, and it is reasonable to expect that the corresponding maxima at heights of 50 to 60 feet are considerably less, but how much less it is not possible to say with great accuracy. The contour of the ground, the presence of sheltering trees and buildings, and the general topography of the surrounding country, all have a vital bearing upon the wind pressures that may be expected at any given place.

The matter of maintenance is as important as that of design or construction, in providing safety for all time. Non-corrosive conductors, such as copper and aluminum, will give no trouble unless there are certain gases present in considerable quantities, such as occur where there is a profusion of smoke from soft coal or fumes from chemical works. The corrosion of steel, however,

is another matter and a serious one. Galvanizing is an initial protection, but not permanent; and it cannot be renewed. It has a life of perhaps 15 years. Painted steel structures, periodically inspected and repainted, should have a much longer life, probably three times as great for permanent structures. The initial factor of safety cannot be maintained unless corrosion is prevented. The same is true with respect to the decay of timber. Therefore it appears to be an essential part of a crossing contract between a power company and a railroad company to provide for periodical inspections, and to place a limit upon the safe dimensions of structural members, so that the processes of corrosion or decay shall not defeat the original purpose.

Another phase of this problem is a legal one, which assumes considerable importance from the railroad point of view. Crossings on private right of way are under the control of the railroad company, but this is not true as regards crossings upon highways or public roads. The latter in most cases are subject to no further regulations than the state laws impose upon all wire crossings, which commonly specify a minimum clearance and sometimes minimum spans, steel pins and double cross-arms. It becomes the duty of electrical engineers to rectify this defect and point out the dangers. Legislation is much needed to place in the hands of the state railroad commissions the necessary authority to deal with such crossings and properly safeguard them.

Percy H. Thomas (by letter): *General.* The crossing of railroad rights of way by power lines represents much the same problem as the crossing of public telephone lines, the latter perhaps offering the widest exposure of the public to danger. Therefore it would perhaps be well to consider the two cases together.

In general the plan outlined in the paper is sound. It will probably however be found, as in the past, impracticable to provide a single set of hard and fast specifications to cover all cases. Crossings vary greatly, not only in importance and exposure but as well in physical characteristics; from the crossing of a main line railroad by a minimum length span of a power line to the very long span, possibly crossing a river with a little used branch railway line along one bank. Flexibility in the specifications could be obtained presumably by the relaxing of specific requirements where there appeared occasion for such a course, and where local conditions furnish justification therefor. The mutual sense of fairness between the engineers of the power and the railroad or telephone company must be relied upon to arrive at an equitable result in each case, the general specification giving a starting point and expressing the best practice for the average condition.

As an example of varying conditions to be determined on by mutual agreement in any particular case I may mention the thickness of ice to be assumed in calculating break down strength.

While it may be well as a matter of principle to provide for the furnishing of full drawings to both parties, and serving long notice of construction with the idea that the company being crossed will check up all details of the design, experience will undoubtedly show the precaution to be omitted in a majority of cases.

Specific Points in the Specifications.—As one of the most dangerous possibilities is the burning off and dropping of a conductor, as by the puncture of an insulator, it may in some cases be well to support the span by a second auxiliary insulator which may furnish mechanical support even if the line conductor be elsewhere grounded.

In cases of wooden cross arms where the nearby spans utilize ungrounded pins it would be well to ground the pins for several poles on each side of the crossing as otherwise lightning reaching the line near the crossing might find an easier ground path at the crossings insulator which must have a grounded pin.

¶8. Guys properly installed should be considered as forming part of the strength of the structures. This applies as well to ¶12.

¶23. The requirement of a special insulator at the crossing while entirely reasonable in one sense will cause a great deal of labor in many cases and perhaps disproportionate expense. if for example a special structure for the tower were thereby required.

It is an open question whether the interlinked type of suspension insulator or the concentric type is really safer in preventing the dropping of the line in case of trouble. The weakness of the interlinked type is the ease with which the link may be burned off if the insulator is punctured.

¶26. This clearance around the insulator seems a little excessive and hardly necessary in all cases.

¶27. This section should be so worded as to clearly permit well galvanized steel.

¶28. It will not always be feasible and it will often be trivial to equalize the strain in the span conductors at the cross over.

¶32. This section is not very clear.

¶33. The serving should extend to some distance on each side of the insulator.

¶35. This maximum wind stress seems too high for cylindrical surfaces; the value 12 has often been used. Of course in special localities the higher value may be warranted.

¶36. Taken in connection with all the other allowances made for safety it would seem safe to use a higher portion of the ultimate conductor strength, especially with a stranded conductor, than 0.3. For instance, 0.4 or even more has frequently been used. In taking extreme precautions in so many features an excessive total may be reached.

Nothing is here specified about the simultaneous conditions that shall be taken to represent the most severe conductor strain.

A. H. Babcock (by letter): Mr. Mershon considers that the two spans adjacent to the crossing span should be constructed under the same specifications as the crossing span. Usually these two spans are on private rights-of-way with which the railroad company is not concerned, unless a mechanical weakness in these spans shall be the cause of a failure in the crossing span, a contingency paragraph 10 is expected to cover. In some cases where the power company plans have been submitted, a head guy towards the tracks has been requested on the two outer poles of the adjacent spans. These combined with the guys mentioned in Section 10 effectually guard against mechanical troubles in the spans adjacent to the crossing span. His suggestion that there may be cases where it would be safer and better to have the power wires pass under the existing wire does not seem practical. Usually power companies object strongly to having any kind of a wire suspended over their circuits; and certainly were I in charge of the construction force of the railroad company I would not care to have my men stringing telephone or signal wires over a live high tension transmission line any more than I think the power company's engineers would like to have railroad line crews so engaged.

His objection to paragraph 20 probably comes from a hasty reading of the said paragraph.

The objection to paragraph 25 does not seem to be well taken since the paragraph states distinctly "of the interconnected link type or its equivalent." It is doubtful that any cemented type of insulator will stand a rifle ball and not drop the line, whereas an interconnected insulator, especially if located a considerable distance from the power house, can be completely shattered and not drop the line; furthermore since these insulators are specified for only a very few spans of the whole transmission line, their unit cost may be many times that of the other insulators used and not increase the total line cost materially.

His objection to paragraph 26 possibly will disappear if the provisions of this paragraph are taken into account in connection with paragraph 29. The size of the conductor specified for the lower voltages in paragraph 27 was intended to cover distribution circuits such as are commonly used in this section of the country where No. 6 copper has been found satisfactory. It is not usual to use wire of this size in long distance transmission line work except for unimportant branches. In these cases it is hardly likely that sufficient current to burn off a No. 6 copper wire could be forced through it.

He states that he is not quite sure what paragraph 32 means. Perhaps its meaning will be made clear by a statement of the fact that in the operation of the large net-work in Central California no form of automatic circuit breaker as yet developed has given satisfaction, and it is the custom to operate these circuits tied in solid to the power house without any automatic

devices intervening. Under these conditions it is evident that a grounding of the conductor when it comes down will be of considerable value, though it has not been found in practice that any grounding device installed at a distance from the power house will burn off the conductor.

I am glad to have my attention called to the possible ambiguity in paragraph 35. Up to this time it never had occurred to me that anyone would think of adding the horizontal wind and the gravity forces in any other fashion than as a geometric resultant.

Mr. Fowles' suggestion that the railroad company shall hold periodical inspections of the power company's structures in the crossing span strikes me as being a good arrangement provided the railroad company does not thereby assume any legal responsibility whatever for the safe operating condition of the power company's structures.

His suggestion that the conductivity and diameter of the conductor at the crossing shall exceed that in the main line by at least 25 per cent does not seem to me necessary for such transmission circuits as are operated in this part of the country, for the reason that it is practically impossible for any generating system to force into a net-work enough current to fuse any wire that is used. If any strengthening of the conductor at the crossings is needed, therefore, the reasons are purely mechanical, in which case it is proper to increase the ultimate strength of the section by a certain per cent, (say 25 in order to be consistent), rather than to increase by a stated amount, the diameter of the conductor, the material of which is not specified.

For many years I have agreed with Mr. Thomas that it is impracticable to provide a single set of hard and fast specifications to cover all cases and have consistently endeavored to have every crossing contract brought up as a separate matter. The table which forms the last paragraph of the original paper will show how difficult and how cumbersome this procedure can become, and after a number of years experience it was found desirable to draw up a general set of specifications, such as are here presented, for the guidance of the power companies in submitting their plans; and to require of them the submission of the detailed plans and specifications called for in paragraph 2, and the notice specified in paragraph 3, so that the railroad company may have an opportunity to check the details. Should Mr. Thomas ever appear before the Southern Pacific Company as engineer for a transmission company about to install a crossing with the railroad company's right-of-way he will find that detailed plans and specifications will be required by the railroad company and that his designs will be most carefully checked before the crossing contract is signed. In an organization less complete and less comprehensive than that of the railroad company this precaution might be neglected; but the Harriman lines organization is more military in form than is

usually found in commercial enterprises. The division superintendents are held personally responsible for all such matters and they would no more dare permit an unauthorized crossing to be installed and maintained over their lines than would a subaltern manoeuver his command independent of the orders of his superior officer.

Mr. Thomas considers that the guys installed should be included in the calculations of the strength of the structures. Doubtless this is necessarily so in the case of the wooden pole construction, otherwise the structure becomes bulky beyond all reason; but in the case of steel structures it would seem desirable not to include the guys in the structure calculations but to have them as an additional safeguard.

Mr. Thomas' objection to the requirements of paragraph 23 does not seem to me to be well taken because the cost of a large insulator on possibly two or three spans of a long line is certainly out of all proportion to the cost of possible damage of a single failure of the transmission line at this point. In the East it may be an open question whether the interconnected link type of suspended insulator or the concentric type is really safer in preventing the dropping of the line in case of trouble, but experience in the West has shown distinctly that inter-link connection of this kind will not burn off in case of line trouble, unless such connections are very near the power station.

It is rather curious that Mr. Thomas should find in paragraph 26 an excessive requirement while Mr. Mershon finds the same paragraph to be too lenient.

I cannot agree that paragraph 27 should be re-worded to permit of well galvanized steel. Under no conditions, especially around sea-fog belts, should galvanized steel conductors of any kind be permitted to cross the railroad company's right-of-way.

Mr. Thomas is the only engineer so far who has objected to the provisions of paragraph 36. A conductor strung with a factor of safety of $2\frac{1}{2}$ will be found to lie in a very flat curve, much flatter than is usually met with in practice. A safety factor of even $3\frac{1}{3}$, such as is called for in the specifications, gives a reasonably flat curve, and in many cases the ordinary line construction as installed at ordinary temperatures, shows much higher factors of safety than are herein required. The requirement of paragraph 36 is intended to cover excessive strains produced by low temperatures or high winds.

I regret that Mr. Mershon's paper "Transmisison Line Crossings over Railroads"—*Railroad Gazette*, Feb. 7, 1908, and Mr. Fowles' paper presented two years ago before the Association of Railway Telegraph Superintendents, were unknown to me before these specifications were written—first, that I might have had the advantage of their experience, and second, that I might publicly have given them credit for such information from these papers as may be found in the specifications.

In conclusion I have to express my obligations for assistance

to Mr. E. B. Katte, chief engineer, Electric Traction, New York Central Lines, and also to Mr. Joseph T. Richards, chief engineer of Maintenance of Way of the Pennsylvania Lines, both of whom have favored me with copies of their standard specifications.

DISCUSSION ON "CARBON FILAMENT LAMPS AS PHOTOMETRIC STANDARDS". JEFFERSON, N. H., JUNE 28, 1910. (SEE PROCEEDINGS FOR JULY, 1910).

(Subject to final revision for the Transactions.)

C. P. Steinmetz: The paper is extremely interesting in giving the history of the development of the standard of light and also showing the accuracy with which the present arbitrary standard can be reproduced and can be maintained indefinitely.

I believe, and the authors of the paper also undoubtedly believe, that the history of the standard of light is not concluded, but that the last step in the development of the standard is still to come: the reduction of the present arbitrary standard which depends on duplication of existing standards, to an absolute standard which can be reproduced without any reference to anything existing. Such an absolute standard would not be used directly for photometric measurement, but the purpose of an absolute standard is to give a means of checking the working standard, so as to guarantee us against drifting, because, after all, a standard reproduced by comparison ultimately will drift, whether in ten years or a century.

It is the history of all the standards which are now established, that they have passed through four stages. I remind you of the standard of length—first we had the period of utterly arbitrary standards, a period which has ceased with all nations, except with the English speaking nations—where we measured the length by the King's foot, or fathom, or yard, or mile, or rod, or some other one of the two hundred units of length. Then came the period of enthusiasm, where we attempted an absolute standard in the meter. We defined the meters as the ten millionth part of the quadrant of the earth. Then came the period of disillusion, when we found that the meter is not an absolute standard but differs therefrom by an error, and we realized that if we remeasure any number of times, we never could get it exactly correct, and there must always remain an error, though small, and so the meter again became an arbitrary standard. That is the period in which the standard of light is at present. Then came the fourth period, where the arbitrary standard has been reduced to an absolute standard, by checking it against a unit of length, which is always reproducable; for instance, the wave length of the helium line of the spectrum. This last period is still to come in the standard of light

We have had the same development in electrical units. Consider for instance, the unit of resistance. First we had an arbitrary standard in the Siemens' unit. Then came the absolute unit, the ohm, representing the period of enthusiasm. Then the international ohm as an arbitrary unit, and now the calibration of the international ohms in absolute standards, which may be reproduced, and guard against drifting of the working standard. This calibration is obviously feasible only at a very few places with specially equipped laboratories.

Now, that fourth period is still to come with the standard

of light. It was for this that, some years ago, before a previous convention, I recommended another form of absolute standard which would afford a means of checking the arbitrary standard of the incandescent lamp, against an absolute value, which can always be duplicated with proper laboratory facilities. In this respect, I do not agree with the authors that it is almost impossible to do it. I think it is quite possible to do it, although it may be difficult.

The proposition was to establish as a standard of light, the radiation energy of one watt, composed of three different frequencies of light, of definite proportion and definite frequency. We realize that such a standard of light can not be used as a working standard, but it would be possible for a number of laboratories, such as our National Bureau of Standards, or the Reichsanstalt in Germany, to produce such a standard, and thereby guard against any drifting of the present arbitrary standard. This fourth period I hope will come, but at present the work done and reported here guarantees against rapid drifting, that is drifting within our generation.

A. E. Kennelly: I think we are much indebted to Dr. Rosa for pointing out the steps by which it has been possible greatly to increase the precision of national and international measurements of candle-power in connection with incandescent lamps.

The first step lay in discovering that, at constant watts, the illumination given by a lamp at a distance was very much steadier than either at constant voltage or constant current. The second point was in regard to eliminating, or reducing as far as possible, the blackening, as mentioned already by Professor Robb. That was also discovered by Dr. Fleming some time ago. It is a very important consideration.

The third important point is that of putting two photometers in tandem, so as to obtain measurements more quickly by reduplicating observers, and so that the lamps need not be operated upon for long intervals of time in making a number of measurements.

The fourth point is in preparing automatic mechanism for eliminating the amount of labor required in making a comparison, so that by pressing a button, a specially ruled paper gives correct measurements by inverse squares, without having to make computations.

The fifth and final point is the reduction of the mean error by having a large number of observations on a number of lamps, and by a number of observers, so that, although the eye is very much inferior as a measuring instrument to the galvanometer of the wheatstone bridge, or to the electrical apparatus, nevertheless, as Dr. Rosa points out, it is possible at a single time to obtain a precision on one lamp of one part in five hundred, by to having half a dozen lamps measured almost simultaneously, bring that precision up to one part in one thousand, and by taking groups worked by four different observers, to bring it still lower.

Discussion on "The Developed High Tension Net Work of a General Power System", San Francisco, Cal., May 5, 1910 (See Proceedings for April, 1910.)

(*Subject to final revision for the Transactions.*)

Markham Cheever: One of the most serious problems that to-day confronts the engineer of an extensive transmission system is the automatic disconnection of disabled lines and apparatus. As the author points out, the fullest utilization of station capacities and the best general regulation of voltage can only be obtained by operating the whole system in parallel. However, the occurrence of anything abnormal at any one point causes a disturbance over the whole system.

Most of the large transmission systems have been a matter of gradual growth, the extensions being made to meet particular requirements, rather than to conform to a comprehensive scheme. It is thus that complicated net-works have arisen, making extremely difficult the satisfactory application of automatic switches. The general experience with automatic switches installed to cut out only the disabled section of transmission line has been unsatisfactory, but it is gratifying to note that relays have been designed to meet the conditions found in one large eastern transmission system and appear to be operating with success. The effort toward maintaining continuous service involves a thorough consideration of the arrangement of trunk lines and feeders, as well as the development of relays that will perform their function properly.

A Member: There is one point on which I would like to ask for information from the eastern engineers and that is the extent to which automatic disconnection devices are used on high tension lines or connecting on to sub-lines or sections of the main line in cases of trouble. I would like to know the class of device that is used for that purpose, and whether it is operated simply by means of relays, operating trips and compressed springs, or whether a small storage battery is used for operating solenoid controlled switches.

President Stillwell: The first instance that I know of, in which the problem of cutting out automatically at both ends a short-circuited feeder was seriously attempted, was in connection with the underground cable system of the Interborough Rapid Transit Company in New York. In that system the Manhattan Power House and the 59th St. Power House are tied together by eight triple cables No. 4/0 B. & S. gauge, and as each station contains nine alternators capable of developing 7500 kilowatts each, and about three times normal current on short circuit, the conditions imposed by short circuit in the cable system are extremely severe. During the development of plans for the Manhattan, the fact that without some such device a cable failure at practically any point might tie up the entire overhead transportation system of New York was realized and discussed, and some of our leading engineers took the position

that the possibilities of trouble were such that the use of a high-potential system of distribution from power house to substations was not justified. It was suggested as an alternative that the power be supplied from a number of independent direct current systems.

The automatic circuit breakers first tried were not satisfactory. They were of the type in which one element is connected across the line through a transformer. They generally failed to work for the reason that a heavy short circuit dropped the voltage to a point where they became inoperative.

In the case of the Manhattan substations each is supplied through at least three cables and in most cases five are used. This permits the use of an actuating device for the circuit breakers which depends not upon potential, but upon difference of current flowing in the short circuited feeder and in the other feeders which supply the substations.

Devices of this kind have proved very satisfactory, and now a short circuit in a feeder cable very rarely, if ever, causes trouble in power house or substation. The automatic circuit breakers operate effectively to disconnect the feeder at both power house and substation.

When I became connected with the Niagara Falls Power Co. in 1907, I found in operation a service to Buffalo, supplied through transformers, which increased the dynamo potential from 2200 to 11,000 volts. There were metallic devices at the 2200 volt terminals of the transformers, and also at their 11000 volt terminals. In Buffalo the step-down transformers were similarly equipped, and a short circuit in Buffalo usually blew all four sets of fuses.

The first step that we took in the direction of remedying this was to devise the time-limit circuit breaker, which is now extensively used in power house work. Andrews at Hastings, England, prior to this time, had devised and used the reverse-current circuit breakers, but we did not attempt the use of these at Buffalo.

I see no reason to doubt that it is possible to equip such high-potential networks as you have here in California with automatic overload and reverse current circuit breakers, which will be effective in reducing largely the interruptions of service due to short circuits on the line. In the Carolinas, the Southern Power Co. now has some eight hundred miles of interconnected overhead circuits and have experienced considerable trouble from lightning. The engineers of the company are beginning, as Mr. Downing is here, to make experimental trials looking to improvement by means of automatic circuit breakers. It is good economy to spend even very considerable amounts of money to avoid interruptions of service. They hurt the business and limit materially the rapidity with which the transmission of electric power is being developed in competition with power locally generated.

I should like to ask Mr. Downing a question which relates to the matter of frequency. Some ten or twelve years ago Professor Perrine, then consulting engineer to the company which installed, as I understand, the first plant of the many which now constitute the system of the Pacific Gas & Electric Co., called upon me at Niagara and invited suggestions regarding frequency. I advised him to adopt 25 cycles as being better adapted than 60 cycles to transmission over great distances, pointing out that such systems always grow far beyond the original scope contemplated, and that with the increase in length of circuit, difficulties due to impedance drop would become very weighty. Those installing the plant to which I refer ultimately decided to use 60 cycles, and I should like to ask Mr. Downing, whether, from his present experience, which has covered so wide a range, he would choose 60 cycles if he were to take this matter up *de novo*, or whether he would use a lower frequency. I should also like to ask him about interruptions of service. Any information Mr. Downing may see fit to give relative to these subjects, I am sure would be highly interesting and useful.

L. R. Jorgensen: With eleven different hydroelectric stations to feed into a common network, the continuity of service depends more upon the character of the network than it does upon the character of the power stations. Generally the hydraulic conduit is the weakest link in power generation and transmission, but not so in this case where we have many plants delivering power into the same system. In case of electrical trouble on the system the affected portion is cut out so as not to disturb other portions of the network. If this selection of the affected portion can be done automatically, it is the quickest and easiest way. The larger the system of transmission lines, the more difficult it is to lay out a system of automatic overload switching that will work satisfactorily. In any system, however, it can only be of advantage to have the incoming feeders to substations provided with inverse time-limit overload relays. These relays will work exactly as intended, if the whole substation load can be taken from one feeder at the time, or, if not, the different feeders should feed separate bus bars or separate sections of bus bars. In case, however, the different feeders and bus bars must be paralleled in the substation, the inverse time-limit overload relay would not work at all times as intended, and the reverse-current relay should be substituted. But, if the installation can be made to suit the former relay, it is the best, as the reverse-current relay has not reached the end of its development. The inverse time-limit relay, however, is entirely reliable. Whether the outgoing feeders from the generating station, feeding a complicated network, should be provided with automatic overload relays is a question that perhaps must be answered in each case by trial to find out if the automatic feature does more good than harm.

E. F. Scattergood: There are three or more points which I would like to speak of in a suggestive way. Mr. Downing spoke of the pin type insulator. It has been demonstrated to the satisfaction of engineers in Southern California, at least two or three of them to my knowledge, that on 16,000-volt circuits, affected by fog, the seven-inch two-part mushroom type insulator gives much better satisfaction; that is, the insulator that is spread out flat gives much better satisfaction than the two-part insulator of the same character but with a top section drooping umbrella-shaped. That seems to be demonstrated without question and would simply follow out Mr. Downing's idea of a more open insulator.

The second point is in regard to oil switches. To my mind it is demonstrated quite clearly, that high-tension oil switches should contain a considerable amount of oil; that is, a large cross section of oil on a level with the point of break and a considerable depth above, as indicated by the paper, and that the break should be horizontal; under these conditions the moving terminal is traveling in fresh cool oil if there is any heat at all generated, and at the same time in case there is a partial breakdown on the part of the switch, that is, the formation of gas in the oil at the break, the gas tends to lift, but as there is a large cross section on a level with the break there will be quantities of fresh cool oil banked around on all sides, ready to flow in. So that we have both terminals at all times flooded with fresh cool oil.

The third point is in regard to the telephone system mentioned in the paper. I think you are all acquainted with the two opposite ideas expressed by engineers on the amount of insulation that should be placed on a telephone line in conjunction with high-tension lines. I have heard it stated that one should not use larger than pony glass insulators, in order that there may be leakage of charges which would affect the telephone line. I have heard it stated by well-known engineers that such has been demonstrated. On the other hand it is stated by engineers that there should be strong insulation of telephone lines to avoid their being charged from the high tension lines, especially if on the same poles; and that on a wooden pole line, for example, if the high tension crossarms are put on with lag screws in the center of the pole, and the telephone arm is put on in the same way, using pony glass for insulation, the telephone line will be noisy on account of the lack of insulation.

I want to speak of an instance from which engineers present may draw their own conclusions, because it is not absolutely definite. In connection with the Los Angeles aqueduct we have a telephone line of 250 miles in length, built on separate poles. Notwithstanding the fact that it parallels 33,000-volt power lines, built for Aqueduct construction, along 200 miles of its length. It was built on separate poles and run underground, through well grounded iron pipe, wherever crossing high-tension

lines in order to insure perfect safety in its use by all classes of men engaged in the aqueduct construction. Standard D.P.D.G. glass insulators were used and the indoor wiring at telephone stations was carefully installed on porcelain knobs. My idea was that the line should be well insulated, and when it was completed it was what might be termed absolutely quiet, though paralleled by one 170-mile and one 30-mile 33,000-volt line with grounded neutral and a third power line similarly grounded, of between 50,000 and 60,000 volts, for about 20 miles. An additional point is that one and one-half years after its installation, apparently due to deterioration of the insulation, the line gave considerable trouble from noise.

The fourth point I want to put more in the form of a question. The author of the paper, Mr. Downing, speaks of having no trouble in paralleling these different stations, which were built without expectation of their being paralleled. I understand that he means that there is practically no trouble in operation. I would like to ask if he has made any readings or tests to ascertain how much power is being lost in the connecting lines, due to the current necessary for keeping the stations in parallel, aside from the current which would exist there, due to the load. I know of one instance which has since been corrected, but which existed for a while in Southern California, in which a 1500-kw. unit at a considerable distance, tended to hunt a little and sometimes more, and in several instances, when it was carrying as much as 900-kw., it was pulled off the line without the other stations experiencing increase in load. I might say that the hunting in those instances was not sufficient to disturb the system for good operation and good service, yet was bad enough to lose the whole output of that generator up to 900 kw., in a distance of some 40 miles.

W. F. Wells: The conditions in the east are somewhat different from those of the west, and yet you may be interested with a few of the various details. The company with which the speaker is connected operates two generating stations, having a total capacity of 48,000 kw. The current is generated at 6600 volts, 25 cycles, and the transmission lines are all underground. These voltages may seem low even when it is considered that the entire distribution system is underground. These two stations are operated in multiple and all of the substations, about twenty, are connected to the one 6000-volt network. The general method of handling the current is similar to that described in the paper, and which has been used for the past eight or ten years. In order to prevent accidents a very strict code of rules has been prepared and each employe operating in a generating plant or substation, receives one of these rule books, for which he has to sign a slip stating that he has received and read the same. There had been some cases where an employe claimed that he did not know a certain rule was in force, and the court decision in case of accident was adverse to

the company. For that reason, both the company with which I am connected, and others in Chicago and New York, have issued these rule books, which are very simple, and which give the general rules pertaining to operation, so that each employe knows how far he may go in any matter. Reliability is the most important thing as shown by one instance. The company has a contract with the City of New York, in which there is a penalty of $500 per minute for interruptions of service, in case current is desired. The transformers used are all of the air-cooled type, no water or oil cooled ones being used. In regard to the switches for these voltages, we have had the same trouble you have experienced on your high tension switches. The present type manufactured by the two large companies operate satisfactorily up to a capacity of say, 40,000 to 50,000 kw., but where the station capacity goes beyond that, and in the case of a short-circuit near to a station, the results are liable to be disastrous.

Reverse-current relays in the cable system are always operative as there is a storage battery in practically each and every one of the substations, thereby insuring a sufficient supply of low-tension current at all times. It is stated in the paper that the horn type arresters are set for a voltage of 25 per cent above the normal. It has been found on our system that voltage surges frequently approximate 100 per cent beyond normal. That probably is due to the greater capacity of the eastern underground cable as compared with the western aerial lines.

John Harisberger: I would like to ask Mr. Downing what experience he has had in opening the switches on the transmission line. The present practice is to cement pins in to the insulator. It would be a splendid idea to use an iron pin in the insulator. I have found that very satisfactory.

P. M. Downing: There is a question in regard to cementing the iron pin to the insulator. In the Puget Sound district, we have practically abandoned that practice by using a threaded iron pin for 60,000 volt service, and have found it very satisfactory.

A. M. Hunt: There is one minor incident in operating transformers that has come to my attention which I thought I would mention. It might be of value to some of you in operating work.

At a substation of the Pacific Gas & Electric Company located at a prominent manufacturing extablishment, there were located three 100-kw., 60,000-volt transformers. It was found that one of the water cooling coils was leaking slightly. It was a very serious matter to shut down the plant. After thinking the matter over, I rigged up a syphon so that the coil could be kept under minus pressure, and it was operated that way for twenty-four hours in order to keep the plant going. Of course, in such a case the leakage would be from the oil side to the water side, and if serious would reduce the oil level, but in this case the leakage was not sufficient to be serious.

A. O. Austin: The extremely variable conditions effecting line insulation on this system have been pointed out by Mr. Downing, and it is in regard to insulators for these conditions that I would like to say a few words.

It was in connection with insulators for these lines that the writer started experimental work which resulted in the development of the high efficiency disk suspension insulators, which have been installed on the largest lines during the past year. Most of the insulators on this system, in addition to having a large percentage of the surface protected, have large variations in diameter throughout the leakage path, and in addition, have the surfaces of highest resistance, limited by small striking distances. This, with a high electrostatic stress on the small shells is the cause of the great depreciation in insulation as the insulator becomes coated with dirt.

The present insulators on this system were the best that could be had at the time they were installed; manufacturing conditions, however, have improved rapidly within the last few years, and it is now possible to make high efficiency insulators which do not depreciate to the same extent when coated. With high efficiency insulators, I believe it possible to insulate these lines so that it will not be necessary to clean the insulators. The high efficiency designs are small for the rating, and are so designed that the surfaces are cleaned by the wind and rain to a much greater extent than the low efficiency insulators.

With the high efficiency designs, it is also possible to provide the line with a much larger factor of safety, the suspension insulators permitting of practically any factor of safety as regards line insulation. The suspension insulators in use on the Pacific Coast are of low efficiency type, having some of the faults of the present pin type insulators, and it is to be hoped that high efficiency insulators will be installed under the same conditions, so that comparisons may be made when insulators have assumed a permanent working condition.

C. F. Adams: There are one or two points which I would like to bring up, one is the subject of the oil switch, and Mr. Wells has just described the ordinary results from the over loading of the switch under service conditions. I presume he refers to what is ordinarily known as type H switch. The chief trouble that occurs is that which seems to be due to the compression of gases in the cylinder, which is too small to contain those gases, resulting in an explosion. The particular switch which is illustrated in the paper, is built upon the theory that the necessary thing in an oil switch is a sufficient depth of oil over the arc that results from opening the switch, and also sufficient area for venting the switch. The entire rim around the top of the tank is vented by a series of holes giving a resulting cross section of several square inches through which any gases may escape. In actual practice this theory has worked out far better than the idea of allowing the gases to compress and thus extinguish the arc by pressure of oil.

There is another feature in Mr. Downing's address on which I had hoped to hear from the manufacturers. There are two types of construction of high-tension transformers. The original high-tension transformers were constructed on the theory that the potential between the high- and low-voltage windings was a possible source of danger; in other words that a break down in the high-tension windings might be communicated to the low-tension windings resulting in a break down of the distributing system, and for this reason the barriers between windings were made more or less fire proof in their nature—micanite being used a great deal.

That theory has been abandoned, though many cases have been found in which local short circuits in high-tension coils have not extended beyond the limit of the coil, and have not burned through the barriers. In later construction the press board insulator has been used entirely, overlooking this feature of transformer construction, and the barrier simply serves the purpose of directing the flow of oil between the various coils.

Another feature of insulation which he discusses is the water absorbing possibilities of the material. For many years the manufacturers went upon the theory that the oil which would enter the partitions would be sufficient to exclude the possible admission of moisture. This theory has not been borne out by practice, and in fact, it is practically common knowledge that press board thoroughly saturated with oil has a continuous affinity for water that may be in the oil; from my own observation I have found that partitions immersed in oil, after a period of some months, would be found to have this peculiar quality: at the upper end of the partition the insulation might withstand 65 or 70,000 volts, while at the bottom of the partition, the thickness being identically the same, the same partition would break down at from 25 to 30,000 volts, and this insulation feature was practically dependent upon the depth of the immersion in the oil, or the height from the top down.

P. M. Downing: In reply to the several inquiries that have been made, I will endeavor to answer them as well as I can.

The first is by the chairman as to whether or not, if we had it to do over again, we would select the same frequency. I endeavored to bring out in the paper that one of the hardest problems that an engineer had to contend with in the operation of a long distance transmission line was the holding up of the voltage on the end of the line due to the inductive drop. It can be overcome to a very great extent by the use of a lower frequency, and after the experience which we have had, it seems to me that I would seriously consider a lower frequency before adopting the 60 cycle.

As I stated in the paper, practically all of these plants were built with the idea of operating as independent plants, and not with the idea of ever being tied into a net work such as we are operating to-day. It is for that reason that we fixed upon

60 cycles, and there is no question in my mind but that the lower frequency would be better.

The second point brought up by the Chairman is as to what part or portion of the load can be taken up by turbines operating in parallel with the system; referring now to the particular system which we have been discussing, we do not attempt to take up the entire load. The steam plants are located at the more important distributing centers, where the service is of most importance, and we only attempt to pick up that important service, and do not try to handle the entire load.

President Stillwell: Is that picked up automatically, or do you have an interruption of a minute or so until you get started?

P. M. Downing: Ordinarily it is picked up automatically, that is, without interruption to the service other than a drop in the voltage.

In reply to Mr. Scattergood's inquiry, as to whether or not there was any appreciable amount of power taken to keep the different stations in parallel—that is rather a hard question to reply to, for the reason that it can only be determined by getting all of the load off the line and seeing what was being required. This, of course, is out of the question, and for that reason I do not know. We do know, however, that there is no great amount of wattless current circulating between the different power houses—practically no current whatever through the neutral of the high-tension transformers, such as was discussed this morning in Mr. Rhodes' paper.

Mr. Harisberger brought up the question of the necessity or desirability of insulating the metal tank of the oil switch from the ground.

This practice is the result of experience dating back a number of years to a time when the art of manufacturing satisfactory insulators was in what might be called its infancy.

The porcelain manufacturers were unable to furnish an insulator that could be relied on to stand the break-down strains to ground even on comparatively short lines carrying light loads.

We are to-day able to get a much better grade of porcelain, and in such shape that it is much better adapted to our requirements, but notwithstanding this fact, the duty imposed upon the switch is much greater than formerly, and the necessity of taking every possible precaution in the way of insulating correspondingly increased.

Insulating the tank from the ground gives an additional factor of safety by cutting down the voltage strains on the bushing insulators entering the switch. Nor have we yet heard any good reason why they should be grounded.

It is claimed by some engineers that grounding the switch tanks is desirable on account of safety to persons coming in contact with it. To a certain extent this is true, but I think the instances where men are required or permitted to work around high voltage switches with power on, are so few that it is unwise

to sacrifice the efficiency of the switch in order to provide the additional safety, desirable only under what might be considered extreme emergencies.

The particular air switch referred to by Mr. Harrisberger is a horizontal break, pole type switch, consisting of contact jaws mounted on line insulators with a connecting blade rotating in a horizontal plane. The three moving blades are connected together and controlled by a single rotating shaft operated from the ground.

It was designed to be used as a disconnecting switch on small transformer installations, or on branch lines where there is little or no current to be broken. It was never intended that it should handle currents of any magnitude.

DISCUSSION ON "HYDROELECTRIC POWER AS APPLIED TO IRRIGATION", SAN FRANCISCO, CAL., MAY 6, 1910. (SEE PROCEEDINGS FOR APRIL, 1910.)

(Subject to final revision for the Transactions.)

President Stillwell: The possibilities opened up by the application of electric power to pumping water for irrigation in California, are obviously very great. A recent publication by the United States Geological Survey estimates the available water powers of California at 7,000,000 twenty-four hour horse power. Assuming twelve tons of coal per horse power pe annum in 24 hour service, that power would require for its production by steam, 84,000,000 tons of coal, which happens to be approximately equal to the anthracite output of the coal mines of Pennsylvania. So vast an output of power, if utilized in manufacturing, would supply a very much larger power market than even California can hope to develop in many years. It is peculiarly interesting that many of these powers exist within practicable reach of land requiring water for irrigation.

A paper which was read at the recent Irrigation Congress at Albuquerque by Mons. Tavernier, Chief Engineer, Department of Public Works, Republic of France, deals with this subject and its conclusions are particularly interesting when considered in the light of similar experience by Mr. Hays and his company. Mons. Tavernier reaches the conclusion that even considered from the standpoint of power economy, it is frequently not more expensive to use water power to operate dynamos, which in turn operate motors lifting water by pumps to the land which requires irrigation, than to distribute water by ditches. According to his figures, the efficiency of the two processes in many cases is practically identical.

E. W. Paul: I would like to ask Mr. Hays in regard to his table given in his paper. I don't quite understand it. He has a plan here of eight and ten acre groves, ten years old, and to irrigate that requires a two h.p. motor. The experience of farmers in the south, with which I am familiar, is that they do not want to irrigate one row of trees at a time, but they want to flood the whole orchard at once. This requires considerable water. I do not think that a two h.p. motor would do that. I would like to ascertain whether they do irrigate the entire ten acres, or do they sit up all night changing the water from one row of trees to the next. I would also like to know if the company with which he is connected requires the motor to be taken off the line on the peak load, and if it does, how they overcome his objection to that feature.

J. C. Hays: The two h.p. motor is correct. Some of them have small reservoirs which will hold the water, and they run that motor continuously 24 hours, and they do irrigate probably ten or twelve rows a day from this little reservoir made of dirt, in some cases, they irrigate a very few rows at a time as they go across their orchard, and they figure that this flat rate will

keep them all the time. This dry bog country has to dry out before they can cultivate it. As to taking the motor off on the peak load—as irrigation is the only peak load we have, they work all the time.

F. V. Henshaw: Mr. Hays describes an electric power system which was apparently built entirely on a fore knowledge of there being sufficient underground waters to enable the plant to get its business by pumping for irrigation, and presumably before going into this project, the extent of those waters was very carefully determined. I think it would be interesting to learn from Mr. Hays the extent to which the underground waters of the San Joaquin Valley have been examined, and whether today it is known that there is a sufficient supply there, in all probability, to irrigate all of the land that cannot be covered by surface waters by gravity distribution. Another point occurs to me, regarding the cost of construction; Mr. Hays says: "If constant service is not absolutely necessary, what possible type of construction can compare with the flume?" I take it that the flumes are built very light, and the point is as to how long an interruption the farmer can stand under extreme conditions. We will say an orange grove, which is at a point where it needs the most water—how long can it be without water without serious damage.

J. C. Hays: I do not know the extent of the underground waters in our state. I have read several papers and reports on the subject but believe that the only way we can tell is to pump.

F. V. Henshaw: I thought you had been doing that.

J. C. Hays: Well, we have in some places. But you can hardly call that conclusive. We have been pumping in one district for ten years, and apparently the supply of water is not diminished. So t naturally looks like there is something there. The water shed of the valley is large enough to take care of the underground waters, and the formation of the deltas in these rivers is of such character on the east side that the water percolates very slowly. On the west side, I understand, there is a different condition where the water flows out very fast; consequently, we are liable to find variation in the wells, but there is a very little variation in the wells on the east side.

F. V. Henshaw: Did you find any wells that had a flowing head?

J. C. Hays: Yes, in what I call the valley portion. But artesian wells are not considered very good for irrigation. I personally do not know much about that subject, but I do know that there is sulphur, or something deleterious in the water, and I know of one peach orchard that was killed by it. As to the subject of the flume—I don't know just how long an orange orchard could go without water. They claim in that country that if they do not irrigate for about two weeks in a very hot season, the trees commence to show it. Most of the growers

claim that they can look at the trees and tell when they need water.

An interruption on the flume or the line, for instance, would not amount to over 24 or 36 hours, possibly 48 hours, and an interruption of that length would do no damage. Of course, during certain portions of the year, landslides cause some damage, but I do not remember of any landslides occurring during the irrigation season. They always occur in the winter time, and never during the irrigation season.

H. Homberger: The Mount Whitney Power Co.'s system is of particular interest to the hydraulic engineer, being a power system where 80 per cent of the power is generated hydraulically and 70 per cent of the power used for pumping. How entirely different the conditions are from those of the average commercial plant with a mixed load, has been most ab'y and clearly explained. There were a few points mentioned which I should like to be further enlightened upon.

First, the question of high price permanent construction as compared with low price temporary construction. It was stated that engineers of prominence have broadly condemned the wooden flume and the wooden pole line as compared with the tunne and steel towers or reinforced concrete poles. Such a stand can only be explained by entire disregard of special conditions; there is no greater danger n engineering than unwarranted generalizing of principles of construct'on and wrongly applying what is good in one case to some other case where it might not fit in at all. Personally I am not in favor of wood as construct'on material and would rather see an inorganic material used. To be sure, 20 years is a remarkably long life for a flume, and I think not to stand alone with the statement that half that is nearer the average. Similar are the conditions with a wooden pole line. It seems to me, however that generally too much stress is laid on the difference in first cost and the fact not taken in consideration, that considerable expense is connected with the necessary continuous patrolling and maintenance of such structures, which if capitalized, would go a long ways towards providing for the higher first cost of a more permanent type of construction, which, as stated, will ultimately have to be resorted to anyhow.

A second point: Balancing reservoirs were mentioned at the head of the pipe lines; while the reservoir of the latest plant, the Tule River Plant, has sufficient capacity to operate the plant $1\frac{3}{4}$ hours under full load, at the Keweah No. 1 station it holds out only 25 minutes and at Keweah No. 2 even less than 19 minutes, which is certainly of little value in case of trouble in the gravity conduit system. The ma n function of the latter two reservoirs is stated to be, to smooth out the diurnal fluctuations in the steam flow, but even a reduction of 2 per cent in same would empty the reservoir, if the plant is to be kept under full load for 24 hours, which is practically the case during the

pumping season, as shown in the daily load curves Fig. 4. Maybe I did not understand this correctly and I should be thankful to have it explained.

Third: With an average load factor of 50 per cent the fixed charges on a hydroelectric plant must be quite high, and with the stated low rates for power it would be interesting to know, whether a large capacity steam plant to be operated during the irrigating season would not make a better financial showing than an additional hydroelectric plant with ten miles of conduit. This might be advantageously located in the Coalinga oil field region, only about 10 miles distant from Visalia, as it might prove more economical to ship current by wire than oil by rail or pipe line.

L. Jorgensen: In general the hydraulic conduit is the weakest link in power transmission for the reason that, from a financial standpoint, it cannot be installed in duplicate. Therefore, on systems with only one or two power plants it is most important to have this link well built. Tunnels are not the only safe conduit, but concrete pipes completely buried are in most cases just as safe, cost only half and require less grade, due to their better hydraulic shape. It is true that a flume costs only about half as much to build as a concrete conduit costs to install, but, if the depreciation, maintenance and interest on the investment are taken into consideration, their cost will be the same. Then the question of whether to use a wooden flume or a concrete conduit is simply a matter of whether the greater amount of money required to cover the first cost of the concrete conduit will balance against the additional safety connected with the use of a buried conduit. How tunnel compares in cost with either wooden flume or concrete conduit will depend upon how much of a short cut it makes. The first cost per linear foot may be four times that of a flume of the same carrying capacity, but a flume or concrete pipe line must follow the contour of the hillside, whereas a tunnel cuts through the hills.

Where the country is flat and otherwise adapted for ditch construction, ditches will be the cheapest, as maintenance cost is lower than for flumes, and depreciation is practically zero. Wooden stave pipes will accomplish the same as concrete pipes and have a lower first cost. If buried they are protected against rolling boulders, frost, etc., but their life is very short and repairs are difficult to make. Taking it all in all the concrete conduit does not seem to be as extensively used as all its good properties should warrant.

E. W. Paul: I would ask Mr. Hays if, on some of these circuits running to pumping plants, he has made any provision on the customers' premises to take care of the motor in case the current goes off the line, that is, as to voltage switches, and also how he even gets farmers to sign the contract described, with the conditions mentioned in his paper?

Ralph W. Pope: I am familiar with the territory where this plant is situated that has been developed for the raising of oranges. I was there twenty years ago when most of it was devoted to the production of wheat. At the time this plant started or a little earlier, the soil had deteriorated owing to continuous wheat cropping. I understand from the author that the soil was exhausted only about four or five inches down, so that orange culture is now pursued with great success. Referring to Mr. Henshaw's inquiries in regard to the pumping, I understand that pumps were formerly operated by windmills or gasolene engines, and that wells had already been dug, so that the question was not whether water could be got there, or not; because it had already been obtained.

There are certain tracts however where the water cannot be reached by digging or boring. The only value pertaining to such land is the possibility of selling it to eastern tenderfeet, which is another source of revenue not mentioned by the author.

In regard to the light construction of this plant, it must be remembered that at the time it was started, while having the water power, something like 7000 h.p., I believe that the question of a market was rather problematical, and ordinarily that is one of the most important questions to be considered in developing a water power plant. It was for this reason that the cheap construction was used in this particular instance. Those of you who are familiar with railroad construction throughout the country know that in early days the construction was frequently of a very cheap character in comparison with what it is to-day. Railroads at that time were an experiment, but as the importance of proper construction developed, and rebuilding was undertaken it was found advisable to strive for permanency. This paper indicates that it is a long, slow process to develop an enterprise of this kind, but when it is permanently established it becomes an attractive investment, if you can find a territory where these conditions prevail. In Utah, I think they need something of this kind, as they have used up about all the water power that is available in that state.

Markham Cheever: Answering Mr. Pope's inquiry regarding the conditions in Utah, underground waters occur in large quantities in the fertile valleys of Utah Lake and the Jordan River, and artesian wells are numerous. However, this water is not used for irrigation to any great extent.

Utah Lake is one of the largest bodies of fresh water in the West and forms a natural reservoir from which the canals of the Jordan River Valley are supplied. As the lake level lowers during the summer, the outflow is maintained by means of large centrifugal pumps. Several projects involving the pumping of water to land lying at a considerable elevation above the lake are contemplated and one is now in operation. While hydroelectric power is used or proposed for all these pumping propositions, the load is not as satisfactory to the power pro-

ducer as that of the project described in the paper, on account of the much shorter irrigation season in Utah.

F. V Henshaw: I would like to add one word, that this matter of underground water is a very essential thing to anybody contemplating going into an enterprise of this kind. I can say positively that in some parts of Colorado, the subject has been very thoroughly investigated and the water is not there. I would like to tell you where, but am afraid it would hurt the feelings of some "eastern capitalists."

A. J. Bowie Jr.: This load curve is different from any others I have seen in that there is no peak in the evening. This is of nterest in matters of rrigation, since the value of the power which can be supplied, of course depends on the nature of the load curve and how the power is used. When the peak comes in the evening the power company can afford to supp y power very much cheaper to the farmers who will shut down at that time. The oad for irrigation differs from other types in that it is possib e that suitable arrangements may be made to cut it off for a few hours a day without suffering serious inconvenience. This is particularly true where small reservoirs are used, reference to which has already been made, and the value of these reservoirs I consider of very great importance in the problem of irrigation. These reservoirs should hold about a day's supply for the farmer, who by that means is enabled to employ his water at such hours as are most advantageous. If his pumping stat on is small, he may use his entire supply in a few hours, instead of having to devote the entire day to the use of water. These reservoirs constructed of earth, are used in a great many parts of the country, and sometimes they are lined when the earth is unsuitable for holding of water. One form lining consists of coal tar, lime, and sand, spread on half an inch in thickness. I have also seen this lining applied where the reservoirs without it would not be able to hold water.

These reservoirs cut down very materially the size of a plant which it is required to install, as well as the corresponding additional investment and they avoid all night irrigation. The economic consideration of irrigation requires a suitable proportioning of the various items of expense which make up the cost of pumping, which may be segregated as (1) the cost of fuel or power, (2) the attendance and (3) the fixed charges, as well as the cost of applying the irrigation water to the land. The sum of these charges should be reduced to a minimum. In irrigating plants the depreciation is generally high. I think, allowing for all fixed charges, 20 per cent, would often be a low figure to cover interest and depreciation repairs and renewals. It is not unusual in countries where fuel and labor are cheap to find the fixed expenses exceeding the other two expenses. A small reservoir would avoid this and be a considerable saving in this way.

In Southern Texas the average depth of irrigation water used

annually was 2.7 feet for all crops, while for alfalfa it was 5.7 feet. The efficiency of most of the pumping plants in that country was exceedingly low. That would apply to any country where plants of a similar type were employed. The cost of pumping an acre foot of water one foot high was four cents, and as the power to raise an acre foot of water one foot high is equal to about one water kw. hour, this would amount to about 4 cents per water kw. hr. This is an average of course.

It may be of interest to you to know that we have quite a little irrigation in the Eastern states for truck gardens. The depth of water employed there depends on the source of supply and the cost of obtaining it, and varies from four to eight inches per year. Many farmers are using city water irrigating to an annual depth of about four inches. This costs for water about $25 per acre per year, where as when pumped water is used, about twice the depth is used at the same cost per acre per year. The average increase in crop values per acre due to irrigation, and allowing for wet and dry years, is about $200 per year over and above all expenses. In other words this is the average net profit of the farmer from irrigating. Of course that is large, but the crops raised per acre are of great value, in some cases going as high as $1500 per acre per annum, so that it does not take very long even in a wet year to make a substantial gain.

W. A. Doble: I think Mr. Hays' excellent paper has been somewhat misunderstood with reference to the cost of this Mt. Whitney plant. We must bear in mind that that was one of the very earliest plants to be built, and was considered at that time the most thorough and best construction that could be done. It was considered that that was the best that could be done at that time. The cash was raised in advance and everything was paid for in cash, and it was put in practically at the lowest rate per horse power of any plant that could be built. The type of construction was not adopted as temporary, but simply because it was the best we knew about at that date. We may deal in generalities on the question of the hydraulic conduit. We cannot say that the flume or tunnel is cheaper or better. The Mt. Whitney No. 1 flume is 30,000 feet long, and a tunnel would have to be 20,000 feet long. The flume is not of large size, and therefore it can be put through at a comparatively small cost, and as the cost for the cross-section of the flume increases, the cost of its construction increases very rapidly. As a tunnel becomes larger its cost decreases very largely. We cannot generalize on those things; each case must be figured out for itself, so that I think a wrong impression is gained. The conditions that surround the Mt. Whitney plant are favorable for the long life of a flume or pole line. The average life of a flume in California is about ten years, and then its cost of maintenance becomes so very great that it is a serious tax. Then, again, we must consider the character of the country we are going through. If it is a country where the slopes are gradual, then it is all right

for flume construction. It is purely a case as to whether we shall adopt a flume, or a ditch, or a tunnel, and that depends upon the country, upon its size, and also as to whether a combination of the two shall be used, using a flume where it is more difficult, and then using an open ditch where it is more favorable. In southern California we have wooden flumes that are now being replaced with reinforced concrete flumes. I will close by saying that I think some of the members have gained a wrong impression of the Mt. Whitney Company. It was started in 1898, and that is ancient history now.

F. G. Baum: Mr. Hays gives some interesting data relative to the method of making power contracts for irrigation service, which should be of use to other companies in similar service. His remarks on the character of the contracts to meet the needs, and also his remarks on the character of the construction to give the service, illustrate the principle that "local conditions" must be taken into account whenever one goes into new problems or attempts to criticize the work of others.

To say that timber face dams, wooden flumes, simply equipped power houses, wooden poles and simple substations are always wrong, and that concrete dams, elaborately equipped power houses, steel towers and elaborate substations are right, only emphasizes the fact that the man making such statements does not take into consideration all the facts. Very often we do not build more permanently for the very simple reason that the money is not available. One builds a house generally to suit his needs and his pocketbook, and a man is not a fool for building a frame house instead of a brick house. We have ferry boats to go over the water before we have tunnels to go under. We crawl before we walk.

As I stated in a paper "Some Power Transmission Economics" at the annual meeting of 1907: "In designing power transmission systems, it is always well to bear in mind that the ultimate development of the art and of the country has not yet been reached.

"In the early days of railroading, the roads and equipment were not of the present trunk-line standard. Light rails, engines and cars, and unfenced right-of-way, and unballasted roadway sufficed. To construct, at that time, up to the present standard would have meant bankruptcy. Even now the manager or engineer, who would build his branch lines of the same standard as his trunk lines, would invite a receiver to take charge of the road.

"The same conditions hold true for power plants and transmission lines. The wise manager or engineer builds to meet existing conditions, looking into the future as far as he can. He cannot afford to build duplicate plants and lines for every case, nor build all his lines on private rights-of-way with steel towers and other refinements and safeguards. He cannot afford to build a duplicate transmission line, at an additional interest

cost of $5,000 per year, when the probability of an interruption, which will cause a loss of revenue of $500 per year to a consumer, is extremely remote.

"It may not be as difficult to determine the proper power station and line to build when unlimited capital and ideal power conditions exist as when there is restricted capital, limited revenue, and low-priced power at the consumer's station. Although in the latter case the amount of money to be expended may be much less than in the former, even more thought is demanded of the engineer; for in the former case, having ample resources, he builds as best he can, while in the latter he must be a judge of conditions and see far ahead, in order that the work which he builds may earn money and at the same time be capable of extension on some plan to meet the growing needs of the country and business.

"On the hydraulic construction and also on the power house and substation installation and construction, the engineer is required to devise something that will pay the largest net income in a given number of years. Sometimes he is called upon to make installations on the assumption that the plant is to be abandoned in a few years. Of course, the engineer will be criticized if he puts in a plant to meet present or apparent future needs and, due to some change in the industry or development of the country, the plant must be remodeled later. But it is the business of the engineer to solve his problems as he sees them."

Much more might be said along the same line to illustrate that construction which may be right for the New York Central R.R., or in the city of New York, may not be right for the Tonapah & Tidewater, or the town of Tonapah.

Engineers must fight the tendency to "build monuments" to themselves. Many of these "monuments" mark the death of a corporation."

Mr. Hays: As to the stream flow and the different reservoirs at power house No. 1, no provision was made for a regulating reservoir when the plant was first constructed, but afterwards, as the load was built up, we found that we had a slight peak; that was back about five years ago, before these curves showed, and we built a little reservoir there with the idea of carrying over the peak load, and as small as that was, it served its purpose very well. On the No. 2 plant, I don't know why that reservoir was put there, it was probably just put there for good measure, and probably because it was a good place for one.

On the Tule River plant we took the matter up carefully as to what size reservoir we should build. We compared the daily load curves with the daily curves of discharge of the river during low water periods and while the stream flow varied to quite an extent during the day it happens to coincide with the load curve. For instance at the height of the peak in the morning the stream flow was greatest and fell off in the evening with the load,

consequently very little if any reservoir capacity was required. The reservoir was therefore built to take care of the fluctuation of the river assuming that the most unfavorable conditions were encountered or that the low water flow would occur at the time of peak load. Also the reservoir has capacity to run the plant until the steam auxiliary may be brought into commission, in case of accident to the flume.

As to the permanency of construction, of course in a case of this kind we are dealing with simple units starting from the motors right up to the power house. The average size motor on the system is a $7\frac{1}{2}$ h.p.—you might say that we were doing a peddling business. The old No. 1 flume that Mr. Doble spoke of was put in for an economical reason, it was far cheaper to put in the flume than a ditch or a tunnel. The flume has been in there for twelve years, and, apparently, with the exception of being water-stained, it is still in good shape. It looks as though it had about ten years more life left in it, and there is no maintenance to speak of required on it.

On the No. 2 plant we have put in a concrete ditch. On Tule River plant we have run in a concrete ditch where the slopes would permit. We also, in that plant, have gone further than the ordinary concrete ditch and do not rely at all on the concrete or on the strength of the bank, the high water level in the ditch being just six inches above the ordinary surface of the slope of the hill. Those improvements that we have put in will eventually double the capacity of the plant, when this ditch and bank have settled down. Also, there are two very long stretches of flume on the Tule River, which some day can be cut out by putting in a tunnel. That flume is of pine, not of redwood, and probably will not last as long as the old No. 1 flume, which has been in use for the last fifteen years.

I don't think that economy could be said to figure in on any one thing with the exception of the main power line and the distributing system. They are all light stuff, all light poles, and they last very well in that country. As to the steam plants taking care of the peak loads, I believe that when the system gets a little larger by increasing the capacity of the present hydraulic plant and in carrying over the peak load by steam, that it will work out all right. Roughly, I have figures on it when the plant gets about twice its present size. We have always considered the present steam plant, simply as an auxiliary. That is a pretty heavy investment to use for that purpose, but as mentioned in the last part of the paper, the company has very much of a responsibility. We have a very large community depending upon a comparatively small power system, and if some accident should put a generating station out of business for a year, it would seriously interfere with a crop. You have to keep some auxiliary ready for all emergencies. Little interruptions do not make any difference. If the Pacific Gas and Electric Company should have its lights go out for fifteen min-

utes between six and seven o'clock at night, it would be a serious matter. For ours to go out between six and seven at night about half of one per cent of the consumers would pay their bill next month and make a "kick" about it.

As to the protection of the motors: That has been one of the things we have been trying very hard to arrange for, and the only practicable apparatus we can furnish is just a straight circuit-breaker, so that when the current goes off, the motor stops, and when the power comes on again, it will trip the circuit-breaker. The average farmer objects to even putting that protection on. All he wants is a fuse. In fact, last year some of our consumers held an indignation meeting because they understood we were obliging them to put on circuit breakers, and they said they would not do it. They held a meeting, and decided that we were trying to get $36 more out of them and they would not stand for it. In fact, we had more trouble with them about that, than we have with them about the contracts. We get them to sign the contracts, sometimes they object, but the contract is absolutely fair. We have to give them a cheap rate, but we work on practically a cash basis. The penalty of one per cent per month provided in the contract is no joke. We actually enforce it, and yet it is not an unusual thing for a man to wait until the end of the year before he pays his bill. Some consumers prefer to pay that one per cent per month interest, and so we allow them to wait until the end of the year.

In operating a pump station I don't know of a single instance in that section where labor costs have been counted. A man generally does the work himself, oils up his pump and looks at his motor about twice a day, goes down into the field, and if the water stops he goes back and finds out what is the matter.

As to the secretary's reference to the underground water, I will say that I do not know of any cases in that section where they have dug for water and did not find it. Some of the growers tried to go up too far into the mountains and there were some wells there that were abandoned after they struck rock, bed rock and granite, and some of them, I presume, never would have reached water.

We have something better for the eastern tenderfoot than the dry lands. We have the "white ash" land, or that which is generally known as alkali land down there, and that sells very well to easterners, and there is more profit in it.

DISCUSSION ON "EMERGENCY GENERATING STATIONS FOR SERVICE IN CONNECTION WITH HYDROELECTRIC TRANSMISSION PLANTS UNDER PACIFIC COAST CONDITIONS." SAN FRANCISCO, CAL., MAY 7, 1910. (SEE PROCEEDINGS FOR APRIL, 1910.)

(*Subject to final revision for the Transactions.*)

President Stillwell: Accepting the reasoning of this paper, it would seem unquestionable that in this case the installation of large gas engine units instead of steam turbine units, was a blunder. The paper can be criticized fairly, I think, in respect to some details of the assumptions upon which its estimates are based. For example, I think that if the auxiliary plant is intended not only to be operated for a short time, in the case of an interruption in the transmission service, and also to be used in conjunction with the transmission of power in case of low water, the unit chosen is too large. The modification, however, that would result from changing the size of the turbines would not affect very materially the annual stand-by charges of the two plants.

L. Jorgensen: Nearly all water power companies of importance have found it necessary to keep auxiliary power plants in their greatest load centers, especially if these are large cities. The units in these plants are mostly steam driven, and, in order to be in readiness for service, part of the boilers are kept under steam at all times.

The expense connected with keeping the boilers under steam is considered to be of less importance than the additional assurance against long interruptions of service. Mr. Hunt has brought out a new device which promises to do away with the necessity of keeping the boilers under fire. This idea seems very simple and possible of application. Where real estate is high, there may be some objections to the extra space required for the heat storage cylinders, as these cannot be installed anywhere, but will have to be located near the boilers, in order not to complicate the steam piping too much.

The space, however, occupied by a plant of this kind will always be less than that required for a gas engine station. Where space water power is available during the greatest part of the 24 hours, electric heaters seem to be very appropriate for compensating for the radiating losses, otherwise it would seem to be more efficient to use super-heated steam (or saturated steam) from the 300 h.p. boiler kept under steam continuously.

Mr. Hunt is very conservative when he allows $33\frac{1}{3}$ per cent for reduced economy in the turbine. It is true that with steam at 25 lb. gauge, expanding to 28 in. vacuum, about 33 per cent less energy is given off, than with steam expanding from 175 lb. gauge to 28 in. vacuum. Therefore, the actual loss would be the average loss, or 16.5 per cent. The turbine should lose but very little in mechanical efficiency if a few tricks are used.

Suppose the steam turbine is a five-stage impulse turbine

designed for best economy at 150 lb. gauge pressure at the throttle. This turbine will still have a high efficiency when working with steam of 175 lb. and 125 lb. pressure. At about 75 lb. pressure the first stage cannot be used any longer and must be by-passed. At this pressure the steam has twice the volume, and, therefore, only about one-half the weight per unit volume as at 175 lb. The energy of the flowing steam is $\frac{m}{2}v^2$ and as the mass at 75 lb. is only half that at 175 lb., the nozzles in the first stage are not big enough to let a sufficient quantity of steam through to pull full load and cannot be made big enough if the velocities of steam are to be right. The velocity v must be kept practically constant, in order not to lose in mechanical efficiency, as all the different blade angles are only correct for one value of v. Cutting out the first stage means a loss of about one-fifth in efficiency, but this loss has already been allowed in the 33 per cent. As further expansion takes place and the throttle pressure approaches 25 lb. it becomes more difficult to keep the velocities in the remaining stages at their correct value. It will perhaps be necessary to work the pumps somewhat harder to increase the vacuum $\frac{1}{4}$ in. or so, not so much for the extra power derived thereform, as this would probably be used by the pumps, but in order to keep the velocity of the steam through the different stages at its proper value. In this way the turbine will not lose perceptibly in efficiency through the whole performance.

K. G. Dunn: I think there should be a further explanation made regarding the title of the paper. This should state that it is under Pacific coast conditions, and it should also state under our present knowledge of gas manufacture.

It is unquestionably true that the thermal efficiency of the gas engine is much higher than the thermal efficiency of any prime mover, therefore, it seems rather paradoxical to state that the efficiency of the steam plant is higher than that of the gas plant.

When we start with fuel, oil, and contemplate that $8\frac{1}{3}$ gallons of oil are required for 1000 ft. of gas, we have a gas generator efficiency of approximately 50 per cent, while a boiler efficiency of 75 per cent with fuel oil is easily maintained, and in that fact lies the increased efficiency of a steam plant over the gas engine plant. I think the estimates are conservative for the gas engine plant. With high hydrogen gas, it is impossible to obtain the economies stated in the paper.

There is another point which comes under the head of hot water storage, that we suggested for a plant something like five years ago, which was to put in electrical heaters in connection with each boiler, these heaters to be placed in circulating pipe, the action being similar to that of a house boiler. One of these heaters and circulating pipe would be connected to each individual boiler, and they could be left in service without interfering with the installation of the plant at all. There is a plant on the

coast to-day that is making up designs and working this proposition, out, and unquestionably it will make a good proposition.

A few years ago, the transmission companies felt that auxiliary plants were not necessary, but in Los Angeles, San Francisco, Portland, Seattle, Spokane and all of the other large centers and congested districts on the Pacific Coast, each one of the operating companies has adopted the plan of installing a certain percentage of steam auxiliary plants to the total hydroelectric output, and unquestionably we will see developments along the lines as suggested in this paper very soon.

C. L. Cory: Mr. Hunt, in his consistent and careful manner, has with discrimination chosen the subject of the paper, namely, "Emergency Generating Stations for Service in Connection with Hydroelectric Transmission Plants under Pacific Coast Conditions." While what I may say in discussion has no direct application to the principal points in the paper, yet I trust it will have a general application to the subject.

Notwithstanding the definiteness with which the subject has been treated by Mr. Hunt, a man who has given much attention to the generation of power and the use of the gas engine, but who is more familiar with the power situation under eastern conditions than on the Pacific Coast, after reading Mr. Hunt's paper expressed some surprise that the conclusions of Mr. Hunt did not indicate that the gas engine has an important position in the large power generating station.

I have been fortunate in having discussed the application of the gas engine for the generation of electric power with the author of the paper and I wish to draw attention to some of the points showing the difference between the emergency station on the Pacific Coast and the general use of the gas engine as largely used in many eastern industrial plants.

A specific illustration given careful consideration within the past year will illustrate the difference between the conditions discussed by Mr. Hunt and those evidently assumed by the individual mentioned, who from his experience evidently has a great belief in the gas engine. The situation under consideration required the provision of a power plant having a total capacity of approximately 10,000 kw. for the operation of a large copper mine. It had been shown by careful investigation that the body of ore to be worked would keep the mine and mill continuously in operation for a period of not less than twenty years. At the power plant site California fuel oil costs $1.65 per barrel, this price being fixed by a 65-cent cost in the field plus freight. On the other hand, New Mexico coal could be obtained at a total cost of approximately $5 per ton, this figure being obtained by adding to the cost of the coal at the mine the freight to the power house site. The question to be decided was what kind of a plant to install, hydroelectric with transmission line, gas engine or steam driven units.

Ultimately without question there will be a hydroelectric plant installed to work in conjunction with the reserve plant at the mine, but what was under consideration at this time was the choice of type of reserve plant to install.

Upon careful investigation it was found that there were a great many places where gas plants are in successful operation, but none on the Pacific Coast using gas made from our California crude oil. Producer gas has not up to the present been made for large units from California oil. By producer gas I mean gas having a thermal value of from 150 to 200 B.t.u. per 100 cu. ft. If I understand the situation the gas used at the Martin station is the ordinary illuminating gas, having a heat value of from 600 to 650 B.t.u. per thousand feet. The quality of gas used in your gas engines will very materially affect the operation of the engines and the service derived therefrom.

In connection with the reserve station, in this particular instance of the 10,000-kw. plant for the copper mine, the distance of transmission would be approximately 60 miles, and as a result of three separate investigations the complete cost of such a hydroelectric plant would be $250 per kilowatt of station capacity, which would correspond to about $300 per kilowatt which could be delivered. The load factor on the plant will be between 90 and 95 per cent, and under such circumstances it would seem that the water power plant must be given very serious consideration. However, the reliability and continuity of operation in this instance were of such great consequence, as has been well indicated by Mr. Hunt, that the reserve steam station is now being built, and will be in operation before the hydroelectric plant can be completed.

In addition to the points that I desired to bring out regarding the distinction between conditions as set forth in the paper and existing on the Pacific Coast, and those conditions which are quite different where blast furnace gases or producer gas is used in many plants in the East, I have one question to ask in direct reference to the paper regarding the capacity of the steam turbines to continuously carry full load when the steam pressure drops to the comparatively low figure mentioned in the paper, or to question the capacity of the turbines and generators under such low steam pressure conditions to carry the full normal load.

L. L. Johnston: In selecting oil as the fuel to be used in several types of power plants of which comparisons are made, the steam turbo is immediately placed at considerable advantage over a gas engine plant in so far as costs of construction and operation are concerned. The abundance of low priced oil on the Pacific Coast, the high efficiency and capacity of steam boilers when oil fired and the very low first cost of an oil fired steam plant has compelled the adoption of oil as fuel and steam as the type of equipment for a plant in preference to all others.

The writer noted recently a large steam turbo-emergency plant near the city of Seattle within a few miles of coal mines and

where coal is cheap. Yet this plant was fired with oil shipped from California.

It has been shown by estimate and experience that the gas engine can make the best showing only where fuels are comparatively expensive or where a low grade of coal or lignite must be used for fuel which gives poor results when fired under steam boilers but good results in gas producers. An oil gas producer has not yet been developed of sufficiently low cost and high efficiency to permit its adoption in connection with gas engines for general power purposes.

Considering the above, in discussing Mr. Hunt's paper, the most that can be shown in favor of the gas engine is that it can, under some conditions, do considerably better than set forth.

Regarding the size limit of gas engines having been reached in the largest units now in operation, it will be recalled that the same was said twenty years ago of 15 h.p. gas engines.

To-day there are several hundred thousand horse power capacity of large gas engines in the east. Most of these are in steel mills and in units of 3500 to 4500 h.p. capacity each. One of these units at Bessemer, Pa., has been operating continuously night and day for the past six months with a total loss of only three hours during that time.

Several experienced builders are now developing gas engine generator units of 5000 kw. capacity.

Some years ago when the Martin station was planned steam turbos of 12,500 kw. capacity there were not yet in commercial use. Also, the larger sizes which could have been selected were at that time going through a stage of development and giving more or less trouble, and the best ones required some minutes in which to be warmed, brought up to speed and put into service without damage to themselves. The gas engine had already demonstrated its ability to be put into service in a short time after standing cold.

Considering that the company owning the Martin station was already in the gas manufacturing business, that its gas equipment could be used in connection with gas engines, and with the other above facts in view, it seems logical therefore, that it should have selected gas engines to be used in its electric stand-by plant.

It has been remarked that the principal difficulty with the gas engines at the Martin station is caused by the high hydrogen content of the gas supplied, which has resulted in cracked cylinders.

However, gas engines are operating successfully at a plant in Lebanon, Pa., on coke over gas which contains a greater percentage of hydrogen than the oil gas at the Martin station.

Experience has shown that some designs of gas engines will operate successfully on a gas containing a comparatively large percentage of hydrogen while others will not. Also that some designs of gas engine cylinders will crack from various causes while others will not.

The fact that the gas engines at the Martin station have been in a state of overhaul so much of the time since their installation looks bad. However, inasmuch as the design of engines is different from the successful ones now operating in this country, the trouble must be laid to a design which has not yet been perfected. Had the engines been of the same design as those in the eastern steel mills, the results might have been quite different, the plant a welcome place to visitors and its merits discussed by engineers throughout the country.

Taking up the several comparisons in the order given by Mr. Hunt.

1. *Comparison of First Costs.* The first cost of the steam plant is favored in that it consists of only two large sized units. Should one of these become disabled only 50 per cent of the plant would remain for service. While in the gas plant about 92 per cent would remain should one unit become disabled.

It appears that the steam plant should have an additional turbo-unit to make it more comparable with the gas plant. On this basis the steam plant would cost approximately $72 per kw. of capacity on a 25,000-kw. rating.

Regarding the cost of the gas making station $1,000,000 appears rather high tension though the writer has no costs at hand to show otherwise. However, it must be remembered that the gas generating station of the Martin plant forms a part of the company's domestic gas manufacturing equipment and contains much apparatus, that would not be required in a strictly power gas plant. The gas generators there have a rated capacity of 3,500,000 cu. ft. of gas per day each and can be pushed to 4,000,000, or, each unit can supply gas for more than 9,000 B.h.p. capacity of engines. This large capacity of gas generator units should contribute toward a low first cost of the plant. These gas generators are simple in construction and consist principally of steel shells 16 ft. in diameter, lined with fire brick and filled with brick checker work.

Considering the fact that at the Martin station the gas plant forms a part of the company's domestic gas equipment and that several large gas holders and relay gas generators are necessary in any event, it will be seen that the first costs and operating charges against the gas engine plant can be materially reduced below those given.

Estimates have been prepared which show that large gas engine electric stations comprising engine generator units of the largest size used in the eastern steel mills, together with coal gas producers, can be constructed complete for $100 per kw. A similar plant but with oil gas producers, especially if constructed in connection with a domestic gas manufacturing plant should not cost more than $100 per kw.

Considering the above, the first cost of an oil fired steam plant would be approximately 72 per cent of that of an oil fired gas engine plant.

2. *Comparison as to Rapidity of Getting into Operation on the Line.* In this comparison it appears that the possibilities of the gas engine have been neglected.

Special consideration is given to the general design and appliances for the steam plant to facilitate its economical construction, operation and quick starting, namely; the plant is designed with only two large sized units; a storage battery supplies the exciter current. Heat storage tanks supply steam instantly, and an arrangement is devised by which all the boilers may be started simultaneously from a central point.

In order for the gas plant to maintain its record of starting in 30 seconds, it is pointed out that twelve engineers would be necessary, also an equal number of men at the switchboard.

There are several movements necessary to start a gas engine, all of which could be operated from a central point by a device similar to that described by Mr. Hunt, to be used in connection with his steam boiler plant, and all of the engines could be started and brought up to speed at the same time.

Regarding the problem of synchronizing a number of gas engine generator units, it is possible by having the exciting current flowing in several generators, to start them all and bring them up to speed in step. With this method of paralleling, combined with starting all units from a central point, it would be possible to start the entire plant as one unit and put it into service within 30 seconds and with a minimum of engine and switching labor.

3. *Comparison as to Standby Charges.* Based upon the foregoing figures it will be seen that the costs of a gas engine electric plant when operated in connection with a domestic gas manufacturing plant can be reduced considerably below Mr. Hunt's estimates.

4. *Comparison as to Costs of Continuous Operation.* Several years ago Mr. H. G. Stott, before a meeting of this Society in New York, called attention (TRANSACTIONS A.I.E.E. 1906), to the high economies possible to be obtained with a combined plant consisting of part steam and part gas equipment, so arranged that the waste heat from the gas part could be utilized toward generating steam for the steam part. The advantages in first cost and fuel economy of such a plant are so marked that it appears that any estimates for plants in which gas engines are considered, should cover this type of plant rather than a straight gas engine plant. The highest efficiencies attained in steam practice are accomplished largely by returning for use all possible waste B.t.us. with the assistance of economizers, feed water heaters, condensers, etc. Similar refinements in gas engine plants have not yet come into general use. However, they are being developed along the lines now followed in steam practice.

The oil gas generators at the Martin station are not as efficient thermally as they might be if designed especially for power

purposes. Much heat is now wasted to the atmosphere in the process of heating the brick checker work and in cooling the gas which might be utilized in generating steam for auxiliary power uses.

The writer has prepared estimates showing comparative costs of a steam turbo plant and a combined steam and gas plant both using oil fuel. In the case of the combined plant it is assumed that the waste heat which can practicably be recovered from the gas engines and gas generators is delivered to the steam part of the plant in feed water. Also, that the lamp black resulting from gas making is burned under the boilers of the steam plant, together with the necessary fuel oil.

The assumptions are that each plant will contain 25,000 kw. capacity of equipment; the combined plant consisting of 15,000 kw. capacity of steam and 10,000 kw. of gas equipment. The combined plant is arranged so that the gas part runs continuously at nearly full load while the steam part handles the variable load and peaks. Also spare units would be included in the steam equipment.

The first cost of the steam equipment is taken at $65 per kw. and the gas at $115 per kw. on this basis the excess cost of the combined plant over the straight steam is $500,000.

The annual costs show that the combined plant can make a saving in the fuel item of $117,152 over that of the steam plant. However, on account of the higher fixed charges of the combined plant, the total annual net saving over the steam, amounts to only $55,153. This saving by the combined plant will pay 11.1 per cent interest on its excess cost.

This saving is perhaps not sufficient to warrant the construction of a combined plant under the conditions assumed. However, should a combined plant be constructed in connection with a gas manufacturing plant under conditions similar to those at Martin station, the first cost of the gas engine plant could be somewhat less than shown above. Also the labor charges against the gas engine plant would be somewhat less. Estimates for a combined plant on this basis, and assumptions similar to those above, taking the cost of the gas equipment at $105 per kw. and the steam at $65, show that the combined plant can be constructed for an excess cost of $400,000 and that its annual saving will amount to $73,000. This saving will pay 18 per cent on the excess cost. This should be sufficient to warrant the construction of such a plant and considering that this is based upon oil at $1.00 per bbl., which price may advance, there should be ample margin for safety in such a conclusion. Further economics could be obtained by returning to the power plant the waste heat from the gas manufacturing part of the plant.

The combined plant as estimated will give 266 kw-hr. per bbl. of oil.

While there are some conditions where steam turbo plants are

obviously better suited, it would seem that all considerations of large fuel power plants should include a close investigation of the possibilities of the gas engine.

A. H. Babcock: It seems to me that in this gas engine discussion, as in many others of an engineering nature, we engineers are prone to look at the economics in a physical sense and not enough toward the economies in the financial sense. The court of last resort in regard to such things is the balance sheet.

Mr. Hunt, in his paper, has mentioned 650 B.t.u. gas as used in the engines in the hypothetical station he has constructed. It seems to me that his figures need a little revision in this particular, and that it will be safer to work with gas not quite so rich. When gas as rich as 600 or 700 heat units is ignited in an engine cylinder there is a real explosion, whereas producer gas of 130 or 150 heat units ignited in a cylinder gives a result more nearly in the nature of a push; the one is like dynamite, the other is like old fashioned black powder. We have heard a great deal about the high hydrogen content of the gas used in the Martin station engines as the origin of much of their trouble. It seems to me that the very rich quality of the gas has more to do with the difficulty than the hydrogen.

Mr. Johnson has been investigating gas engine projects on the West Coast for the last year, and is, therefore, especially qualified to have an opinion on them, particularly with reference to the economic side. He has found in many cases that while there are very cheap fuels available, and a high physical economy of the plant can be shown, the high first cost of the machinery and apparatus produces fixed charges so high that the physical economies of the processes are entirely wiped out, as far as the balance sheet is concerned. It seems to me that we are much in the same position with relation to our water plants, especially where there is more water in the securities than in the hydraulic systems, and it is my opinion that it is possible to construct a steam plant, oil fired, almost anywhere on San Francisco bay and compete successfully with the highly capitalized long distance transmission line power. I am aware that on many balance sheets the matter of fixed charges is not taken into account as it should be, and that reports made by engineers to financial men are misleading frequently in this respect. It is immaterial whether we ignore these fixed charges entirely, or whether we transfer them to the next generation, the fact is that they must be paid some time, and therefore it is misleading not to take them into account in our financial statements.

K. G. Dunn: I would like to call attention to one fact that should be taken into consideration when comparing gas engine plants with steam plants. In a gas engine plant, there is no possible overload capacity whatever. In the ordinary steam plant, each unit is capable of a continuous overload capacity of not less than 25 per cent, and it has a peak load capacity of 50 per cent overload. When you take the peak load capacity

into consideration, it is unquestionably true that a steam plant can be installed for one-half the cost per kilowatt.

W. A. Doble: There is one point, Mr. President, I think should be brought out, and that is, that a gas engine or a reserve capacity plant of 24,000 kw. is extraordinarily large, and there are not so many transmission companies that would be justified in putting up a plant of that magnitude. It has occurred to me that the plant should be very much smaller than that, and though Mr. Hunt treats the matter very fairly, I do not think the paper shows clearly that under conditions of one-third or one-half that capacity, that these conditions would be favorable or as favorable.

There is another point with reference to putting in plants of this kind as against water transmission. It is interesting to know in this connection that the Pacific Oil and Power Company of Los Angeles which own its own oil wells, transmits power 129 miles and sells oil. It also uses some in its stations, and is now increasing the number of stations, because it is going into long distance transmission. If we consider a composite plant of steam and gas engines, and then a turbo-unit, I am afraid we would have to make a triple power plant, and then where would we be?

F. G. Baum: My criticism of Mr. Hunt's paper is, not in the conclusions, but in the method presented, which starts out like a debate or argument, presenting in the beginning the statement which it is intended to *maintain* rather than by presenting both sides of the question and then drawing the conclusions at the end. An engineer should be a judge and not an advocate and he should avoid being put in the position where he *must advocate* one side and not discuss and weigh both sides of a question with an open mind.

In both the gas electric and the steam electric plant we burn oil at one point and produce kilowatt-hours at another. But in the gas engine plant there are two inherent weaknesses in the process of developing power.

1. The process of making gas is intermittent.
2. The process of destroying the gas or changing it from gas to mechanical energy is intermittent.

In these two fundamental defects lie the inefficiency of the gas engine process of power development. As a general proposition, intermittent processes are inefficient because they waste more or less time, and because the time is wasted the machine must be larger, and because it is larger, it wastes more time, etc. Hence the cost of the machine increases and the waste time and its by-products become more and more a loss.

To make things efficient we make them "hum," that is, produce a constant *high speed* condition at each instant of time. That is what we do in the electric motor, the tangential or turbine water wheel, the centrifugal pump, the steam turbine, etc. Of all the power units the tangential water wheel driven generator is the simplest.

In the steam turbine process of developing power we have practically a constant condition at each point of the machine for each instant of time, and hence the mechanical conditions for efficiency are good. We also have conditions right for producing units of large capacity, which again is a very decided advantage over the gas engine unit. For constant power in large units (except under conditions where the gas engine burns waste gases) the steam turbine is far preferable to the gas engine and because we can make it " hum "—that is, get the advantage of high speed and constant power, it has certain inherent advantages over the reciprocating steam engine.

The disadvantage of the steam-electric unit for emergency purposes is the delay in getting up steam. Whether the scheme for steam storage outlined by Mr. Hunt is practical or not I do not know, but as he has proved his case on the assumption that it is practical, I presume he has had experience with the scheme. It is an easy matter to prove theoretically the gas engine highly efficient, but in the practice the results may be different; hence theoretical proofs must be backed up by practical results before they can be accepted as final."

President Stillwell: So far as this particular gas engine plant is concerned, Mr. Johnson's contribution to the discussion furnishes a clear and perhaps an adequate explanation. Not infrequently what apparently is a serious engineering blunder results from circumstances purely local and transitory, which properly exonerate the engineer from responsibility.

A. M. Hunt: It was not my intention in writing the paper to indicate in full detail and outline the design of a plant. The estimates have been made simply as a basis for comparison. As a matter of fact, each individual case would have to be considered upon its own merits, and worked out accordingly. I should, in all probability, in designing a station of this character, arrange it in such a way that the water in the boilers would be in circulation in connection with the heat storage, and my reason for not doing that in the paper was this: I had no data on which I could calculate or even approximate the radiation losses from the surface exposed in the boiler, so I cut that out as the easiest way of avoiding the point. Mr. Stillwell as well as several others, have referred to the fact that the steam turbine station is equipped with but two large units, which is not just in making the comparison. This, in a measure is true, but it is partially offset by the fact that in a gas making station, the gas generators are assumed as only three, so if one of them is out of use, one-third of the plant would be unavailable. It may be argued that the gas generator is a machine that does not work all the time. From time to time the gas generator must be shut down and allowed to cool off, the brick work re-set, and so forth; so that, as a matter of fact, in such a station, it might be considered that four gas generating units should be employed.

Mr. Jorgensen, in his remarks, speaks as if the heat storage

proposition were a new element. It is not. I reca'l that back in the '90s, if not earlier, this question of heat storage was discussed in connection with generating stations in England by Mr. Halpine. He worked it out at some considerable length, but what application was ever made of it, I do not know. Mr. Stillwell, says that it was actually employed. In that instance, as my recollection serves me, it was intended to equalize the daily fluctuation of the load on the boiler plant and avoid the necessity of the installation of larger boiler capacity, and possibly getting also higher efficiency.

I am surprised that no one has taken exception to the fact of using the electric heater in the heat storage, although, I believe, some one did mention the fact, that he would prefer to maintain the temperature of the water by using steam from the auxiliary boiler. As a matter of fact, I admit that the electric heater is perhaps what might be called " finicky ", still it could be made of such elemental simplicity, that I believe its use would be justified, at least, in certain cases.

Mr. Jorgensen criticized the increased steam consumption of the turbine under reducing pressure, as being stated by me as too high. I do not recall the details of my calculation on this, and, in fact, I will say frankly, that it was a matter of guess as I first put it down, but subsequently I ran across one of the turbine designers and requested him to calculate it for me and he came back and said, " You are a very good guesser, I worked it out as about 32 per cent," so I let it stand.

Mr. Dunn has made some remark with reference to the efficiency of the gas making process as compared to the efficiency of the use of fuel in the boilers. It is quite true, in reference to the present method used in making gas from oil, and the present method is the only one at this time commercially operative. It is true that a number of people are working on the problem of making producer gas from oil, having a lower heat value, and a higher efficiency, and I know of at least two such processes that are in tentative commercial shape. I should not be surprised to see either of them developed in the near future to a point where they can be given serious consideration, and in such case, the gas engine side of the controversy would be at greater advantage.

Professor Cory, in his remarks, raises the query as to the possibility of the turbine keeping up and carrying the load at the reduced pressure. It is entirely possible, but would, of course, necessitate the turbine being especially designed for the end in view.

Mr. Johnson rather infers that I am not entirely fair to the gas engine in taking oil as the fuel for my basis of operation, and yet under conditions as they exist here on the Pacific Coast, oil is, of necessity, the economical fuel.

Mr. Babcock left the inference that he may have something up his sleeve in the way of near-at-hand supply of fuel.

believe I know myself of certain "pseudo" coal mines in the near vicinity, but I should be afraid to offer any consumer the coal from them.

Mr. Johnson also attempts to smooth down the criticism with reference to the installation of gas engines as the Martin station. It is to be regretted that he must be the one to stand up for the station, but when he states that the gas engines were adopted because they were installed in connection with the gas plant, with which they were manufacturing gas for domestic and other purposes, here, I think he is wrong. I do not think Mr. Johnson was on this coast at the time that plant was installed. That plant was installed, if my information is correct, because it was a necessity at that time, under the conditions of a contract made for the supplying by the Pacific Gas & Electric Company, or its predecessors in interest, that a plant should be installed which would be capable of being started within a given interval of time, and put current on the line, as a guarantee that continuity of service would be afforded. It was not installed to make gas for domestic or other purposes. It was installed solely and purely for power purposes. It is true that if it were installed in connection with a gas manufacturing plant for domestic service, the unit of cost would perhaps be somewhat reduced; but this was not the case in the instance I have in mind. You cannot build a plant and use it both for power service and for domestic service. If the plant is devoted to power service, it must be held for that, and not at any time used on domestic service, except in case of ultimate emergency.

Mr. Babcock takes some exception to my having made the comparison on the basis of gas having such high heat value. I do not know how he would make a gas of lower heat value out of crude petroleum by any present operative process. As I have stated, there are processes in line of development to-day that may lead to that outcome.

Mr. Doble's criticism as to the size of the plant selected for the purpose of comparison is entirely just. There are few plants in existence on the coast that I know of where a 25,000-kw. emergency plant would be justified, but at the same time I do not think the legitimacy of the argument, or the result, would be very much different, even though the size of the plant were quite materially reduced.

Cary T. Hutchinson (by letter): Mr. Hunt justly says of water-power plants, "*absolute* continuity of service is a thing which cannot be secured." This might also be said with equal truth with regard to steam plants or any other kind of machinery. His opinion evidently is that a stand-by steam plant is necessary in order to secure *satisfactory* continuity of service, and that this plant is required principally to guard against failures of machinery, including transmission lines, and not primarily to make up the deficiency in the water supply.

Mr. Hunt proposes a plan which does not by any means secure

"absolute" continuity of service; in fact, it does not provide for as great continuity of service as can be provided by a steam plant. He seeks to lessen the cost of the stand-by service and to this end proposes hot water storage under pressure, arrangements by which the labor is minimized and certain other devices all tending to this, but all on the other hand diminishing somewhat the degree of insurance secured. A steam plant for the most effective stand-by service should have pressure in all the boilers, up to the throttle, auxiliaries in operation and fields of generator excited—indeed, one might even say that the generators themselves should be turning over. The plant also should be practically fully manned, and should have the same capacity as the load for which it is a reserve. If this degree of insurance against interruptions is required, I think it can easily be shown that the most economical way to obtain it is not to build the hydroelectric plant.

The investment cost of such a hydroelectric plant including substation, but not including distribution lines, will certainly be $200 per kilowatt of delivered power and probably greater, say, $250. The total annual cost per kilowatt of plant capacity will be at least $22 and probably more, including interest, depreciation, maintenance and operating expenses. A reserve steam plant of equal capacity, of large units, (and this is the only kind of plant that I am considering) can be installed complete for not more than $75 per kilowatt. The total stand-by charges against this plant, including all fixed charges, maintenance, labor and such fuel as is necessary to keep it in instant readiness for operation, based on a number of detailed estimates made by persons familiar with the conditions of the Pacific Coast, will be approximately as follows, per kilowatt of capacity:

1. Fixed charges	$10.00
2. Labor	2.50
3. Fuel and Supplies	2.50
Total	$15.00

But whatever this amount may be, it is a charge which will remain unchanged if the same plant is used for service instead of used as a stand-by plant. With oil as fuel, the cost of generating energy over and above the stand-by charges already referred to will not exceed 4.5 mils per kilowatt-hour. For an additional expenditure of $22 the steam plant can be operated on a load factor of 4880 hours, that is, approximately 56 per cent, for the same total annual cost. There will furthermore be a saving in the investment cost of $200 per kilowatt; that is, the same gross and net earnings can be obtained for $75 per kilowatt instead of $275 per kilowatt, in other words, the investment for the same gross earnings is reduced to less than 30 per cent.

I think it is safe to say that no competent engineer could possibly advise the construction of a steam plant as a stand-by

station under these conditions, which apply pretty closely to the Pacific Coast.

If such a high degree of insurance against interruptions is not required, the next question that arises is the best way to obtain what might be called " satisfactory " insurance of commercial operation. This could be accomplished in several ways, one being to install a steam plant of lesser capacity than the total, say, 50 per cent; but in this case, of course, there would remain considerable interruptions to service. It is doubtful whether the additional cost involved in a steam plant of 50 per cent capacity for stand-by service only, is justified, and it would seem that the better way is to build a hydroelectric plant without steam reserve of any kind, but in the most permanent way possible, eliminating flumes as far as possible, constructing tunnels wherever feasible, and using reserve generating sets and duplicate transmission lines, preferably on entirely independent rights of way. The records of the Stanislaus transmission would seem to indicate that when properly constructed and maintained such a transmission line on the Pacific Coast is very nearly free from interruptions. If two such lines were built on independent rights of way, the service in as far as this part of the plant is concerned, would certainly be satisfactory.

It is fairly certain, however, that no water-way composed largely of flume can be built that will not give continuous trouble; tunnelling should be resorted to wherever possible. This is dictated not only by reliability of service but also by economical considerations, in many cases, inasmuch as the total annual charges against the flume line, including maintenance and depreciation will frequently exceed those of a tunnel to take its place, as the following example, which is fairly typical, indicates.

A flume line having a capacity of 200 second-feet, probably would cost under average conditions $30,000 per mile. The annual cost of this line for interest, depreciation and maintenance would be not less than $6000 and might be as high as $7,500 per mile. A tunnel of this capacity, concrete lined, could be built for approximately $100,000 per mile; its maintenance and interest would be, say, $6000. The tunnel is, therefore, as cheap, mile for mile, as the flume, but in many cases one mile of tunnel will replace several miles of flume, and the advantage of the tunnel is much greater.

It would seem to me that the best engineering solution of this problem is then to build the hydroelectric plant in the most substantial manner possible, to construct reservoirs of the maximum possible capacity, in order that the water power may be utilized at a load factor of 100 per cent or as near this as it is feasible to bring it, and then to supplement the delivery of the water power plant by a steam plant at the point of consumption which acts as a stand-by plant to the extent of its capacity and also as a peak load plant under daily service conditions. It seems folly to build a steam plant for stand-by

service pure and simple when by comparatively small addition to the annual cost this plant can be used to bring in a large amount of additional business.

The following comparison between the cost of a system of reservoirs to utilize the drainage area to the fullest extent and of a steam plant to make up the deficiencies in the water supply is fairly representative of the Pacific Coast conditions:

Precipitation	60 in.
Runoff, 55 per cent = 2.44 sec. ft. =	33 "
Assume development for 2.2 sec. ft. =	30 "
Runoff for six low water months, 0.45 sec. ft	3 "
Runoff for six flood months	30 "
Use for power during six flood months	15 "
Storage during six flood months	15 "
Needed for power during six low water months	12 "
Remainder lost in evaporation and seepage	3 "
Storage 15 in. equal 35,000,000 cu. ft. per sq. mi	
Drainage area	250 sq. mi.
Total reservoir capacity	8,750 million cu. ft.
Cost of reservoirs, at $200 per million	$1,750,000
Total annual charges, at 6 per cent	$105,000
Head	1,200 ft.
Average flow, 250 × 2.2 sec. ft. =	550 sec. ft.
Average delivered power at sub-station	33,000 kw.
Load factor	50 per cent
Capacity of sub-station	66,000 kw.
Low month discharge, 250 × 0.45	112 sec. ft.
Low month, discharge, of average	20 per cent
Steam plant capacity (say 75 per cent)	50,000 kw.
Cost of steam plant	$3,750,000
Annual cost of stand-by service	$750,000

That is to say, if it were possible to construct reservoirs of sufficient capacity, the entire runoff from this drainage area could be utilized at an investment cost of $1,750,000, and an annual cost of $105,000, as against an investment of $3,750,000 for the equivalent steam plant, and an annual cost of $750,000, a saving of $2,000,000 in investment and of $645,000 in annual charges.

P. H. Thomas. In his heat storage steam relay arrangement Mr. Hunt has given an ingenious and in one sense a feasible plan for maintaining an uninterrupted supply of power on a distribution system. This general subject of relays in power systems is receiving a good deal of attention at the present time and, as seems to be usual under similar circumstances, engineers are inclined to take an extreme view, some one way and some the other. It is the opinion of the writer, however, that the wisdom of the installation of a steam relay plant is not one to be settled off hand without a careful study of the conditions of any particular case. There are cases of course where such relay is imperative but there are also many cases where it would not be warranted.

The absolute necessity of a local relay arises with some sorts of load, as mine pumps, hoists and some work in connection with furnaces of various sorts, but these are exceptional forms of load, and furthermore are usually service for which a relatively

high price for power is obtained. With other systems however, the dominating consideration is different, namely, is that of economy, on account of competing power. In these cases, usually, an occasional interruption, while perhaps excessively annoying, is not a source of very great actual expense either to the company or to the consumer. Of course frequent interruptions have a serious harmful effect on the sales of power. At the present time the standard of our best transmission plants, after the initial starting and trying out periods is good. It must not be forgotten also, that no form of alternative power is entirely free from interruption so that relative excellence is all that is required. It is obvious that the extra investment required by the relay may be very considerable.

It will frequently be found that the real necessity for a steam relay exists only for some few customers so that a relatively small relay will suffice. Such a condition is not so serious. Again the same reliability may be sometimes attained by some alternative method. The high class engineer's most necessary quality, his sense of proportion, should here come into requisition. I do not here wish to be understood as decrying steam relays broadly but merely to call attention to some to their disadvantages and limitations.

What can actually be expected of a steam relay in the matter of preventing all interruption of service? Take the case where the relay is within a few hundred feet of the consumer who is to be protected. If the relay generator is not on the line there will be a certain brief interruption in case of a sudden failure of the main supply, long enough to get the generator on the line and the boilers steaming at their proper rate. If the generator is floating on the line there will still occur the equ'valent of a partial shut down for the boilers which have been banked cannot be momentarily forced to give full steam capacity, without some such storage devise as is proposed by Mr. Hunt. Again if the trouble is one that causes a short circuit or a ground it may open the steam generator breakers or otherwise momentarily prevent its taking up the load. Even in the case of successful automatic circuit breakers there will usually be drop enough in voltage from a good short to throw out any synchronous apparatus on the consumers circuits.

Taking the case where the system is one of distribution at high potential as well as transmission, as is the case in most hydroelectric systems, there will be only one consumer who will get the full protection of such a relay since the others must be fed through some portion of the high tension line and trouble on this portion will cut off the relay.

It is thus clear that only in a few cases will it be possible, by means of a relay entirely to prevent *momentary* interruptions of a consumer's supply and in these actual success would be secured only by the best of upkeep and concentration of effort on this one result.

When, however the elimination of interruptions of the service of some considerable duration is considered, the case assumes a very different aspect. A steam turbine and banked or even cold boilers can be gotten into service and onto the line in less than perhaps an hour, and sometimes much sooner, if planned and operated for this purpose. That is as protection against interruptions caused by serious accidents that more or less permanently disable some part of the supply system and that consequently require time for repair, the banked boiler steam relay will serve admirably, except of course for cases where the injury interrupts the communication between the relay and the consumer. For momentary interruptions on the other hand such as flash-overs on line insulators where no permanent injury is done, the service can be re-established on the original circuits more quickly than a new set of operators can get it started on a new set of circuits.

On the side of the advantages of the steam relay there is much to be said. A system provided with a steam relay is usually much more flexible in operation as well as having the direct advantage of possibility of using the *relay power on regular load*. In fact the most satisfactory basis for the installation of a steam relay is the rendering possible thereby of the sale of increased total power. The well known curve of flow of many streams showing a sharp minimum for a relatively short period of the year, far below the average, limits the maximum sale of power, while with a steam plant supplementing the low water, a much larger sale is possible, supplied nearly all the year around by the hydraulic apparatus. In this well known case the great limitation of the steam relay, its extra cost, is partially obviated, for the output of extra generating capacity in the hydraulic apparatus, which takes the steam load most of the year will not usually add anywhere nearly proportionally to the capital cost. This is the natural use of the steam relay. But in such a case it has in one sense ceased to be strictly a relay, but is rather a supplementary source of power. It will have the strict relay function, however, at times of plentiful hydraulic power.

While every case must depend on its particular circumstances, it is clear that for reasons of capital costs a *steam* relay, at least where no supplementary power is produced, should be installed only where very strong reasons exist therefore. Suppose, for example, that the relay plant installation costs per kw. one half as much as the hydraulic development. This means that 50 per cent will be added to the fixed charges of the hydraulic system, which constitute the chief expense charges of such a system. But more, the expense of banked fires, trying out the steam apparatus periodically as well as the maintenance of at least the skeleton of a steam organization, will add very greatly to the small operating expenses of the hydraulic plant. When it is remembered that the added reliability of service will add little or nothing to the price to be obtained for power, the handi-

cap in the dividend paying possibilities of the plant due to the steam relay are evident. It should be remembered, that exception is to be made in the case of steam relays which supplement a minimum hydraulic power and hence justify their added capital charge by increased sale of power and in the case of mining plants and other plants where a very difficult transmission exists and exceptionally high prices can be obtained for power and practically absolutely uninterrupted services is essential.

This discussion so far is not intended to minimize the importance of reliable service, but is preparatory to raising the question whether some other better way cannot be found to serve the same purpose.

In the first place in important work it is necessary to use only structures and apparatus that are substantial and reliable. No amount of relay will compensate for inferior construction. In the second place alternative lines and apparatus all through a system must be provided, for the purposes of inspection and repairs if for nothing else. Any unit must be spared when necessary. To reduce this additional cost of the spare capacity thus required, the units should be several in number so that the duplication of one unit will not be a large percentage of the total. This applies both to transmission lines and generating stations. Thus the real essential is to have several generating stations of the most available sort rather than one hydraulic and a steam station.

With at least two hydraulic generating stations and duplicate transmission lines following different routes most of the essential *relay* advantages of the steam relay are obtained and the duplicate or spare apparatus forms a part of the regularly effective elements of the system. As long as it is not practicable at most points of the system to absolutely eliminate *momentary* shut downs, even with a steam relay, it is the opinion of the author that in general, with the exceptions already noted, the first effort should be directed toward securing the necessary reliability through good construction and a number of hydraulic stations and duplicate lines following separate routes, if possible, rather than to suffer the duplication of capital in a steam station, to be *used purely as an emergency relay.*

Additional exceptions may be made where a single consumer is given a special relay of relatively small power or where personalities of some sort enter or a steam station is already in existence and can be obtained at small cost.

Mention should be made of the extreme importance of strict discipline and careful organization and planning in advance the procedure to be followed in case of trouble, as well as intelligent superintendence, in actually realizing reliable service.

It should also be remembered that exceptional freshets, land slides, earthquakes, tc., are rather "acts of God" than preventable accidents and are beyond the responsibility of the generating

plant and it is not perhaps necessary or wise to permanently raise the power rates on account of the reserve apparatus capital charges necessary to forstal such catastrophies, especially as they may occur in many and unforseen ways and to guard against all will be prohibitive or impossible. When the maximum load comes but a few hours in the year as frequently happens it is clear that at other times there is plenty of relay apparatus, thus substantially providing against accidents.

In the study of reliability of service, it will be well to put more thought and emphasis on the automatic relay apparatus for separating good from bad circuits and limiting the short circuit damage, for by these great benefit can be done the service at little expense.

To summarize, the purpose of the above discussion is to bring out the point that the real function of a steam relay is to supplement the supply of power so that more kw. can be sold; and that emergency alternative service will best come from the use of several power houses of the most available sort and transmission lines following different routes and by providing spare units for each essential element.

Discussion on "Telephone Engineering Around the Golden Gate". Jefferson, N. H., June 29, 1910. (See Proceedings for June, 1910).

(Subject to final revision for the Transactions.)

Frank F. Fowle: Mr. Smith's paper is a very interesting description of the general features of a large automatic installation, from an operating standpoint. The descriptive nature of the paper does not permit of elaborate discussion, but there are several novel features worth emphasizing.

The ingenious method of checking suburban toll calls, with the " rapid fire " or " express " method of operating, is especially interesting. It does away with the drag on the service caused by releasing the calling subscriber and then calling him back when the connection is ready—a procedure which, as Mr. Smith describes, is only necessary to verify his number and prevent mistakes or fraud.

The problem of a meter for measured service seems to have been solved to the same degree that it has been worked out in manual practice, but it is yet lacking from the standpoint of the subscriber. The only satisfactory solution to the subscriber will be an indicating meter at his telephone, which he can read himself. The means for accomplishing this appear to be at hand, both in manual and in automatic service. There seems to be some apathy towards realizing this ideal arrangement on the part of telephone companies, due no doubt in part to the cost of an extensive change in subscribers' equipment, and in part to a belief that the public does not demand it. On the latter score, the public has been discouraged in some cases into believing that this ideal plan is very costly and difficult of achievment.

Coin boxes for prepayment service have long been in use in manual systems. They have been operated under two plans, one requiring the deposit of the coin to signal the operator, and the other requiring the coin to be deposited after the order has been given, when told to do so by the operator. The former plan is used in business districts, the latter in residence districts, where it might occasion some inconvenience to find a coin in an emergency or late at night. Under both plans, the operator controls the disposition of the coin by means of keys in her cord circuit, sending it into the coin box if the call is completed, or returning it to the subscriber if the call is not completed.

Mr. Smith describes a device by means of which the coin box is employed in automatic prepayment measured service. The coin here is not deposited until the called party responds, and then it must be dropped in the box in order to take a short circuit off the transmitter at the calling station.

This form of service admittedly has disadvantages in public places, stores, waiting rooms, etc., but on the other hand it has admittedly several disadvantages for offices and residences. In view of the fact that this class of service is usually charged

for at a low minimum, it comprises in some cities a large part of the whole development, and considerations affecting it are therefore important.

The functions now controlled at the subscriber's station could be arranged to operate a meter dial and thus register the call within sight of the calling party, thereby doing away with the objections to the coin box in office and residence service. The costs of reading and collecting might be slightly greater than they are with the present system, but not such as to increase the total cost of operation to any appreciable extent. It is quite conceivable that the meters could be read by calling the subscriber on his telephone and asking him for the reading, although in such a case it would be necessary to have duplicate meters in the exchange, as a check.

A meter situated in the exchange, assuming that to be the only meter, is beyond the control or observation of the subscriber, and theoretically this is not the proper place for it, although such an arrangement is both convenient and economical for the company. There is natural suspicion of such a plan on the part of subscribers, particularly when they are unable to check their bills.

Under the proposed plan, the meter should not cost more than the present coin boxes, and probably less. The maintenance costs should also be no greater.

The writer asks Mr. Smith the following questions in regard to automatic practice in San Francisco and Oakland.

1. In the case of manual private branch exchanges, what arrangements are made for night service when no operator is on duty? That is, is there any practice which corresponds to the plan of connecting certain extensions through the branch board to the exchange for night service, as in full manual systems?

2. In the case of manual private branch exchanges, are the extensions equipped for automatic or manual operation, or both?

3. Are automatic, unattended private branch exchanges in demand or in use?

4. Has party line service been developed, and if so, of what classes. Is selective ringing employed?

5. What standard of transmission in terms of No. 19 B. & S. gauge cable with 0.054 or 0.060 mf. per mile, was employed in laying out the distribution, and the toll trunks, for all service in the automatic zone?

Geo. D. Shepardson (by letter): The telephone exchange systems present an interesting case of the gradual displacement of sentient actions by automatic operations which has been going on in most lines of industry. It is common to distinguish between "manual" and "automatic" exchanges according to whether human effort at the exchange is or is not required for performing the various operations of connecting the calling and the called subscribers. As a matter of fact, manually operated

systems use more and more automatically operated devices, and automatic systems require more and more manual operation as they become more and more extensive. The exact stage where a given system shall change from automatic to manual operation or vice versa is a question partly of simplicity of design and of certainty of operation, and partly a question of required investment and of dividend-earning capacity.

The first impulse or judgment regarding automatic telephone systems is that they may be suitable for small towns, but that they are inherently outclassed by manual systems when applied to the multifarious demands of large business communities. It is interesting to learn that practically every service has been met successfully by automatic devices, with the single exception of toll service, where partially manual operation is found desirable. Theoretically the automatic system could take care even of such service, and the probable reason for the introduction of manual operators at this stage is doubtless due to financial rather than to purely theoretical or engineering considerations.

The various checks on measured and toll service are of much interest. The feeling that an automatic apparatus is insentient probably adds greatly to the instinctive desire of customers with weak or perverted moral natures to "beat the company." A somewhat similar tone-test on the line of the subscriber reported as calling for a toll connection might save full-manual systems some trouble from tolls erroneously or viciously charged against an innocent subscriber.

The development of the automatic telephone system has proceeded to a stage that compels admiration. Both the electrical and the mechanical features bear evidence of careful forethought and of fruitful experience. A detail that contributed much to the successful operation of switching devices at a considerable distance from the battery, is the minimizing of friction in the selecting switch by having the plunger move to the chosen position before coming into contact with the fingers or jacks.

An equally ingenious feature of the earlier exchanges was the use of one side of the line for selecting the bank or group, while the individual unit was selected over the other wire. In the later development the successful use of the time element in differentiating between the group and the individual, bears evidence of careful design and development. The elimination of the ground connection doubtless removes a source of considerable stray noise and other trouble. But a question arises as to whether trouble is not experienced in requiring the calling subscriber to observe a certain rapidity in making successive settings of the dial, lest too long an interval result in automatically cutting off the connection before it is complete.

The use of primary and secondary line switches for saving time and trunks seems closely analogous to the development of local automatic exchanges for handling business of a district at some distance from the main exchange, such as are being used as auxiliaries to automatic or manual exchanges.

The mention of difficulties arising from the Chinese method of counting, prompts the suggestion that French girls should make good telephone operators on manual boards having twenty jacks in each row. For, if the French think as they speak, they think in twenties rather than in tens. Thus, instead of thinking of 88 as eight tens plus eight, they apparently think of it as four twenties plus eight, for they call it "quatre-vingts huit." The neophyte French operator would automatically look to or reach for the fifth row of jacks instead of for the ninth row as would be more natural for the ordinary girl.

A point of especial interest in the automatic system as presented in this paper is the simplicity of the talking circuit and its freedom from series impedances and objectionable leakages.

Altogether, the system here presented seems to be a triumph of inventive skill, of engineering research and of financial perseverance and courage.

L. M. Antoine (by letter): The paper is limited to a description of the San Francisco plant and does not touch on the advantages to be derived by the system installed there over other systems originally installed.

A point which appealed to me was the small number of switches used, and the flexible arrangements by which these few switches were made to handle the load. The elimination of all superfluous equipment should carry with it many advantages, such as lower first cost, less floor space, reduced maintenance cost and more efficient service due to less chances for trouble. The latter two points are of paramount importance to an operating company, for a lesser amount of equipment will require fewer switchmen to attend it and can be more carefully watched. At the present time first class switchmen are very hard to get and command good salaries. Practice has shown that equipment in constant use is less subject to trouble than that which is only used occasionally, for dust will collect on contacts and moving parts of idle switches, and make their operation sluggish and uncertain.

Another problem which has confronted operating companies, and which seems to be satisfactorily solved in this system is that of giving good measured service. It is not an easy matter to design a meter that will automatically register completed pay calls only and eliminate incomplete and busy calls, calls to free numbers, etc. It has evidently been accomplished and the device and circuits are so simple that its operation should be positive.

One of the strong points of this system is its efficient private branch exchange service. In Portland, Oregon, nearly 25 per cent of the automatic telephones are stations on private systems of some kind. In the standard private branch exchange the trunks and stations terminate in jacks with lamp signals at a small manual switchboard and each station is equipped with an automatic telephone.

Taking down the receiver signals the operator who connects the calling station with a trunk, or another local station asked for. All local calls are completed manually by the operator, but on trunk calls the station does the calling and releasing automatically. This is a great advantage for when the station has been connected to a trunk the calling party can operate as on a main line telephone, and call as many numbers as he desires without attracting the attention of the operator. Until he hangs up his receiver for a period of time longer than that required to release the call the operator gets no supervision. On incoming calls from the central office the rotary connectors select the idle trunks, as described in the paper under discussion. All are two-way trunks. The board is equipped with a calling device enabling the operator to do the calling if desired.

Automatic intercommunicating service has been perfected to such an extent that it is very desirable in private systems of but a few stations. The operation is the same as that of a manual intercommunicating system, except that the calling is done automatically.

Another kind of service that is growing into favor is that of inter-communicating between extension telephones on a main line. A party on one extension wishing to talk with another on the same line calls an eight on his dial which connects his line to a specially designed switch. This switch sends out generator to ring bells on his own line, and also furnishes talking battery. By using different rings for each extension it makes a very satisfactory office system.

A service which is being extensively used is that of a house system in connection with main lines in apartment houses. The main lines are wired in the regular way except that they are multipled into sets at the vestibules, tradesmen's entrance and janitors' quarters. These sets are equipped with push buttons —one for each apartment—with the name of the occupant opposite. When calling any apartment over one of these sets it is merely necessary to press its respective button to ring. On removing the pressure the push button restores itself part way and remains in a talking position until the receiver is hung up, when the button is restored to normal. All 'phones in apartments are so wired that if a push button is depressed before the dial is rotated the bell at the janitor's station is rung and a drop corresponding to the calling telephone energized. If a subscriber wishes to make a trunk call he makes it in the regular way. As soon as the dial is rotated the janitor signal circuit is open.

Toll service is one of the most essential requisites for the success of any telephone system, for the value of a telephone to the subscriber depends as much on the number of subscribers he can reach as on the quality of the service. When toll traffic is as heavy as it is between San Francisco and Oakland, too much attention cannot be given to the development of an efficient and rapid system. With the system installed at San Francisco

and Oakland the service should be very rapid, for the suburban operator dials the required number and the checking is done later.

A. B. Smith: Answering Mr. Fowle's questions in order, I will state as follows:

1. Private branch exchanges, which are used in connection with automatic public exchanges, are given the same night service as is customary in an all manual plant. Such telephones as it is desired to connect up for the night are equipped with automatic calling devices. They are thus enabled, when plugged up to trunk lines for the night, to operate the automatic switches in the public exchange just as if each were on an ordinary subscribers line.

2. As indicated above, only such telephones in the private branch exchange are equipped with calling devices, as are expected to be used for direct calling. Owing to the simple nature of the calling device, it is an easy matter to equip any manual telephone in the branch exchange so that it will be able to operate the automatic switches.

3. Unattended, automatic private branch exchanges are in demand and are in use in a number of places.

4. For many years party line service has been given by automatic exchanges. The four frequency harmonic system is employed, using 16-, 33-, 50- and 66-cycle currents to ring the bells. Both two-party and four-party service are in use.

5. Since the matter of transmission standards falls within the field of the constructing engineer, I will leave the discussion of this point to Mr. S. G. McMeen.

Professor Shepardson's remark regarding the time element necessary in two-wire automatic operations, requires a little explanation. When the subscriber takes his receiver from the hook, a circuit is closed through the telephone in exactly the same way as in any ordinary common battery telephone. When the dial is rotated to send in the impulses for any given digit, it merely opens and closes the circuit as many times as there are units in the digit; that is, if the subscriber pulls the dial for the figure 3 the calling device would open and close the circuit three times, and would come to rest with the circuit closed.

If the subscriber so desires, he may wait several minutes between successive settings of the dial without causing any further inconvenience than to delay the completion of his call. The release is initiated by the opening of the line circuit which is done by the hanging of the receiver on the hook.

DISCUSSION ON "INTERACTION OF FLYWHEELS AND MOTORS WHEN DRIVING ROLL TRAINS BY INDUCTION MOTORS." JEFFERSON N. H., JUNE 29, 1910. (SEE PROCEEDINGS FOR JUNE 1910.)

(Subject to final revision for the Transactions.)

C. P. Steinmetz: This paper of Mr. Gasche I consider a very valuable and important addition to the records of our Institute dealing as it does with an extremely important problem of motor application, an application, indeed, which I believe represents the most severe service to which electric motors have ever been applied.

When we speak of intermittent load or fluctuating load, usually we immediately think of railway loads. We realize that the load mathematically discussed in this paper, the roll train, is a load in which the fluctuation is vastly more rapid and more violent than in any railway train. I understand that under certain conditions the change from friction load to maximum load, and return to friction load, occurs within less than one revolution of the driving motor. The system which is dealt with in the paper is a system of a power consuming device, the roll train, in which power is consumed at a very fluctuating rate, but with fluctuations which are fairly definite in their nature, a power supply at a rate by which speed and power are related to each other in the well known manner of the induction motor, and the energy storing device, the flywheel. Here we have changes in the condition of the system at such a rate that never during the operation do the conditions, in regard to speed and torque of the motor become constant, that is, the phenomenon with which we have to deal here is not that of stationary operation but is a transient operation, and again here we are in the field of transient phenomena, and if we look at the equations we will recognize immediately the transient function as characterizing the inter-relation of phenomena. Now, transients have one characteristic, that is, the relation of the elements to the system are not determined by their constants alone, but are also determined and dependent on the conditions of the system at the starting moment and at the end of the transition, that is, the so-called terminal conditions enter into the function mathematically as integration constants.

Now, we have two different forms into which the terminal conditions enter, either as independent and fixed conditions, or as relations connecting the conditions of the system, at the starting moment and at the finishing moment of the cycle. For instance, if an electrical circuit is changed by a switch, you have given the previous condition and you have given the final condition, between these two the transient completes its course. A second case is where the terminal condition is related to the starting condition, usually identical therewith, that means where the transient condition recurs as recurrent transient phenomenon. Recurrent transients, as you know

are used in the electrical industry to a large extent for circuit control—in the circuit control which cuts resistance in and out of the motor field periodically. Such recurrent transients are the arcing grounds which we have on our transmission lines, etc.

The recurrent transient which Mr. Gasche treats of so interestingly in this paper is a very much more complex one. The cycle completes, not after two or three steps, as we usually find, but after a very great number of steps, during the passing of the roll train, each being characterized by a rapid change, from friction load to maximum load and back to friction load, next passing from friction load to maximum load, possibly smaller or longer duration than the previous one, back again to friction load, and so on, until finally the cycle closes itself by the last terminal condition coinciding with the first starting point.

This is extremely interesting, and as we all realize, it is a very important problem which is here dealt with. Interesting and important also the subject is, as pointed out by Mr. Gasche in his opening remarks, in another respect—by the nature of the load. The loads here consist of the action of forces within that range from which scientists and theoretical investigators usually keep carefully away, while industrially it is the range of greatest importance, that is, the range beyond the elastic limit, where the action of the forces has become irreversible. We have already spent some time at this convention in studying the range of electric forces at those voltages where the action has become irreversible, where we are beyond the elastic limit of the action of electric field.

Here you have the condition before you when you deal with mechanical forces acting beyond the elastic limit.

We cannot expect too much at once, but I hope you will join with me in expressing the wish that Mr. Gasche may find it possible very soon to complete this valuable information by giving us what is referred to, how to calculate that maximum load by the use of suitable formula and physical constants. It is a field which is of extreme importance, not only in the range of mechanical forces, but also in the range of electrical forces, and all other forces, because here we get information on the nature of the forces, where you are beyond the elastic limit, and it is in this field which is being opened up at present, and up to the door of which the present paper leads and, as we hope, the next paper of Mr. Gasche will lead us beyond the door into the field of that development.

Charles F. Scott: We are always interested to see electricity do big things and new things—our interest in connection with the steel mill has been to see the motor take the place of the engine, the engine which has been capable of quick reversing and handling enormous instantaneous loads. The thing which struck me particularly, as Mr. Gasche was giving the introduc-

tion to his paper, and indicating some of the conditions which he has to meet, were the features which lead away from what has been done before—he was not simply replacing the engine, which used to do something ponderous and impressive, but he was going into an entirely different field and doing something which had not been done before, and something which could not be done before.

The little electric motor which only a dozen years ago was an average street railway motor of 25 or 50 h.p., doing some auxiliary features about the mill and was looked on as a kind of toy, entirely insignificant compared with the main operations of the mill—that little motor has grown until it has become the central feature of the steel industry. Take the power plant—that has changed, we have a new kind of prime mover, one which is not at all adapted to steel mill work, a gas engine, which is a great big, slow moving, constant running, non-overload machine, just the kind of thing that is not fitted for the intermittent speed and power requirements of steel mills.

Going to the other extreme, the requirements in the way of rolls and performance are, as Mr. Gasche points out, simply enormous in the operations of a steel mill; they have never been met before, and in between this otherwise helpless, big, gas engine and these tremendous requirements in the rolls, comes the electric system with the motor, and with one of the simplest kinds of motors, the induction motor. The alternating current generator and the induction motor, the simplest types of generator and motor, come in to perform this marvelous service which is revolutionizing the whole steel business.

The power problem is, as Dr. Steinmetz pointed out, one of the most severe problems which appears in mechanical work. In one sense the problem is of a very elementary kind, in that it does not go into the unknown and involve mysterious features such as some of these electrical discussions that we have had today, involving ions, gases, and one thing and another, but in the rather long table of the symbols which enter into the formulæ we have simply those which represent the most elemental matters in mechanics. There is mass, and length, and time, the fundamental units, and then there is a little more complexity in the case of velocity, etc., and the problem is simply, we may say, the elementary mechanical problem of supplying the proper constants and working out the mechanical elements, which in turn will give the motor requirements, the speed and torque, or tangential forces to be developed by the motor. It is by this kind of language that the requirements of service can be gotten into the nomenclature of the motor, which is simply torque and speed.

To read a paper and hear explanations of these new large forces and requirements is impressive, but it is still more impressive to see the thing itself. In looking at the reversing motors in the South Chicago works of the Illionois Steel Com-

pany some time ago, I was very much impressed in standing and looking at the motor and its great big armature, some five feet in diameter, revolving rapidly in one direction, and then easily and quietly and quickly reversing and running in the other direction, and oscillating back and forth under the control of the little hand lever of the distant operator; and yet that motor and those rolls can reverse, from 4800 kw. in one direction to the same amount in the other direction, in six seconds—and the motor-generator set which supplies the power for variations of that kind, for the loads thrown on and off as the ingot comes in and out of the rolls, is such that the power that is taken from the generator is practically constant within a variation of 25 or 30 per cent. These enormous powers, the ease with which these sudden changes take place, and yet the practical constancy on the circuit, are something to observe, and cause a new wonder and admiration for what electricity has accomplished.

Gano Dunn: Mr. Gasche's work may be regarded in one respect as looking toward the development of a substitute for the storage battery. A few years ago there was brought out, the value of batteries floating on the line to serve as reservoirs of power and to absorb fluctuations. Such batteries enabled large reductions in plant capacity and in line, and enabled great improvements in regulation. Storage batteries, however, are not adapted to the excessively severe service and difficult environment of steel mills for the reason, as Mr. Edison more emphatically than is here permitted, used to put it, that they are wet.

While it is true that we have been familiar with the capacity of a flywheel for storing energy, we have never in the past made such general use of this property as has been recently made in steel mills in Europe and in this country. We have all known that a flywheel running at a constant speed can never deliver or absorb power and that it is only when we slow it down that we can uncover and make it give up the energy stored in it. We have also known the law of the rate at which it gives up its energy or absorbs it, but it has been left for Mr. Gasche to develop and analyze this law when the flywheel is electrically tied to a motor on the one hand, and rolling mill work on the other.

With Mr. Gasche's formulas we have spread out before us, all the necessary relations between motor, wheel and work, that we need to know in making use of the flywheel as a reservoir of energy and as a mechanical substitute for the electrical storage battery.

In sympathy with the paper, I criticize the statement "It will be shown in what follows, that on the assumption of perfectly rigid roll train connections and a rotor without any inertia effect (if such were possible), the induction motor is physically incapable of assuming any roll train load above the friction load that by some means may have been imposed on the motor."

I cannot agree with this. Up to the limit of its break-down torque the motor would accept load even if its rotor had no inertia, and I see no characteristic in the load that would be imposed by the entering of an ingot, that would introduce new conditions that would alter this fact.

The paper also says, "On the larger sizes of roll trains the shock imposed on the rolls and connections due to the action of a powerful motor of small slip, would prove such a destructive agent that the experience would be at least a costly one. The nature of the shock arising at the motor shaft can be understood from the following study of the characteristics of a roll pass."

The shock on the shaft of a big induction motor with small slip can be no greater than the shock on the shaft of the same motor when it has been equipped with a flywheel. The conclusion may follow from the formulas, but the formulas are good only within the scope of their terms, and the ideal case of a rotor with no inertia is probably not properly represented in this case, by the terms.

How much power to take out of a given wheel or how much of a wheel to install for a given power involves a nice consideration of first cost on one hand and annual charges on the other. The key to the problem is the percentage of slow-down.

For moderate slow-downs the energy a wheel will deliver is approximately proportional to twice the slow-down, while the energy wasted by the rotor of the induction motor driving it is roughly proportional to three times the slow-down.

With fixed slip resistance large slips or slow-downs, while involving cheap wheels, mean low efficiencies; and low efficiencies must be charged not only with the power wasted, but with their proportion of the increase in first cost of the plant to supply them. My experience has been that it is really cheaper to put in what at first looks like an expensive wheel and run it at small slip, even where power is cheap. This is dictated by reasons not only of economy but of effective operation, since regulation problems are simpler with small slips and overloads are less disturbing.

Where the flywheel installation absorbs a small proportion of the total output of the power plant of a mill, gradient of load change is of more importance than percentage of fluctuation between maximum and minimum load. For usual mill conditions, which involve relatively long waits between slabs or ingots compared to the waits between the passes of a given slab or ingot, what might be termed the maximum average power consumption is bound to occur almost no matter how big a flywheel is put in.

Even an enormously large flywheel will not continue to absorb power during the whole of the relatively long waits between slabs or ingots, nor will it deliver stored power during

the whole of the relatively long time required for the succession of passes of any given slab or ingot. Consequently the main power plant must be installed to supply the maximum average power required by the work.

The flywheel's duty is to prevent fluctuations from this maximum average rather than from the datum line of zero power and if this view is taken, a moderate flywheel outfit, without attempting to smooth out the fluctuations that occur between successive slabs or ingots, will very satisfactorily smooth out the fluctuations occuring between the passes of a given slab or ingot.

In designing such moderate flywheels the gradient of the fluctuation rather than its absolute amount is the feature to which attention should be given. It is too sharp a gradient that causes noticeable change in the brilliancy of lamps. It is too sharp a gradient that causes synchronous apparatus in the neighborhood to drop out of step. It is too sharp a gradient that upsets the stability of governors in the power house and it is too sharp a gradient that prevents a happy and comfortable adjustment of all the apparatus in the mill to such rises and falls of potential as will occur in the everyday working of a steel mill.

If the gradient is properly taken care of, relatively large fluctuations of power may be permitted and in the ordinary large mill, where there are a number of fluctuating loads, these loads will be found to pool their demand for power so that the fluctuation from the power plant will be surprisingly small.

Where there is opportunity for pooling, it is a useless investment to install flywheels larger than just enough to prevent wide departures from the maximum average rolling load.

Selby Haar: Mr Gasche's paper is of great value at the present time, because it deals with a subject on which there are practically no data on record, so that all engineering recommendations on driving motors must be based on laborious calculation. For this reason, any conception which gives one a broader view of the problem is welcome.

The author has assumed that the torque of the motor is proportional to its slip. The same assumption underlies Mr. H. C. Specht's paper which was read at the Frontenac meeting. This does not affect the nature of the conclusions which have been drawn, and is an almost necessary simplification, but since the torque of an induction motor is not exactly proportional to the slip the variation must frequently be considered, especially if the maximum reduction in speed is specified. The writer has selected a set of conditions and drawn the torque curves to show this.

In Fig. 1, the full line shows the actual torque curve of a motor designed to give twice full load torque at 15 per cent slip; the dotted line represents a curve with the same slip at light load as the full line, while the dot and dash line is drawn so as to show the same torque at 15 per cent slip as the full line.

Fig. 2 shows the distribution of the duty between motor and flywheel corresponding to each of the torque curves. The full line curve was calculated by a method which will be described later, but equations 8 and 23 were used for the other two. Attention is called to the shape of the full line curve for the interval between passes. This is due to the departure of the torque curve from a straight line.

The method of calculation to which reference has been made was developed for rapid work without the aid of any tools but a slide rule after the torque curve is drawn. The theoretical basis is as follows:

T_3 is the total torque to be delivered.
T_a is the motor torque at the time t_a.
T_b the torque at the time t_b.

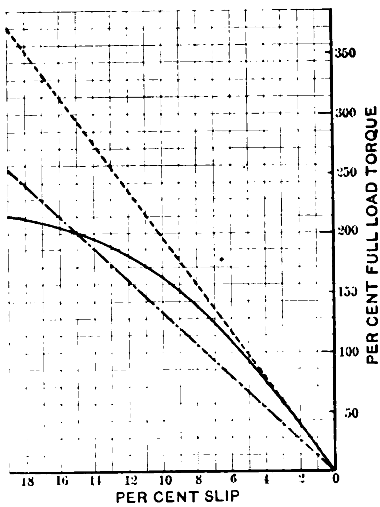

FIG. 1

From the torque curve we get σ_a as the slip corresponding to T_a and σ_b corresponding to T_b. This gives a difference in speed of $(1-\sigma_b)\,v_s-(1-\sigma_a)\,v_s$, and an average acceleration (or retardation) of $-\dfrac{(\sigma_b-\sigma_a)\,v_s}{t_b-t_a}$. The flywheel torque is

$$\frac{M\,K^2\,(\sigma_b-\sigma_a)\,v_s}{t_b-t_a}.$$

Then

$$\frac{T_a+T_b}{2}=T_3-M\,K^2\,\frac{(\sigma_b-\sigma_a)\,v_s}{t_b-t_a}\ \text{for the pass,}$$

and

$$t_b - t_a = \frac{(\sigma_b - \sigma_a)\, v_s\, M K^2}{T_3 - \dfrac{T_a + T_b}{2}}$$

Assuming constant intervals for $\sigma_b - \sigma_a$, say one per cent, we obtain t_b t_a directly. These times need only be summed

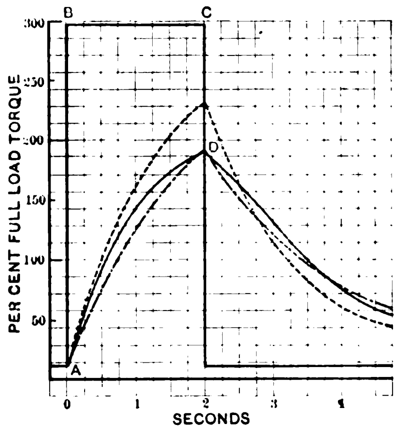

Fig. 2

until the pass is completed. The modification of the formula for the interval between passes is obvious. The attached tabulation shows the method of carrying out the work.

Another point in this connection: The area A, B, C, D, A in Fig. 2 represents the decrease in momentum of the flywheel.

Pass.

Slip	T_a	T_b	$\frac{T_a + T_b}{2}$	$T_3 - \frac{T_a + T_b}{2}$	$t_b - t_a$	Elapsed time
0.0055 0.01	15000	26500	20800	394200	0.042	0.042
0.01 -0.02	26500	53500	40000	375000	0.098	0.140
0.02 -0.03	53500	78500	66000	349000	0.105	0.245
0.03 -0.04	78500	104000	91200	323750	0.113	0.358

etc.

This can be separated into various factors of mass and speed drop until satisfactory division is obtained. It can be used as a check on the other method, or if the point D is fixed and the curve A D drawn in by estimation, the flywheel effect required can be determined directly.

W. W. Crawford (by letter): In discussing Mr. Gasche's paper, it is my purpose to call attention to some of the physical aspects of the interactions covered by his equations, to introduce a short-cut method for deriving the behavior of the apparatus under repeated cyclical loads from its behavior during the first cycle, and to extend the method to cases where regulating devices are used to control the torque of the motor.

The motor operates at constant speed under a constant friction torque until the first bloom reaches the rolls. This applies a sudden, but uniform, load. The motor then approaches a new condition of steady running, which, if the time required for the pass were sufficiently long, the motor would eventually reach. The approach to steady running is retarded by the inertia of the flywheel. The rapidity of the approach is less, the heavier the flywheel, and the greater the necessary increase in slip before the motor will take up the entire torque.

Mr. Gasche's equation 8 shows that the motor torque follows a logarithmic curve which approaches asymptotically to a line representing the uniform load applied. This equation may be put in the following form:

$$\text{Log}\,\frac{T'}{T} = A\,t$$

where T' = initial unbalanced torque acting to change the velocity of the flywheel.

T = unbalanced torque at a later instant.

t = time interval.

A = a constant inversely proportional to the amount of inertia of the flywheel, and inversely proportional to the amount of slip for a given load.

When the load is removed, the motor is developing a torque in excess of the friction load, and the difference is an unbalanced torque accelerating the flywheel. The law of torque variation is the same (see equation 24) as before, when T' and T are taken to represent the unbalanced torques.

Therefore the calculation of any cycle resolves itself into considering the unbalanced torque at the beginning of each element of the cycle, computing from it the final unbalanced torque by means of the formula, and combining this with the rolling torques to obtain the motor torques. The same formula is used in each element since A is constant throughout.

A table of values of the ratio $\frac{T'}{T}$ corresponding to the different time intervals can be made up for a given set of rolls, and the same table will apply for the calculation of any combination of loads to which the apparatus may be subjected.

Calculation by the above method requires that the conditions

at some point, say the beginning of the cycle, are known. Where the mill operation is continuous, conditions at the beginning of a given cycle are not known, being dependent on the previous cycle. The results of continuous operation might be obtained by figuring through cycle after cycle till a uniform condition is reached, in fact, after the first cycle practically uniform conditions will have been reached in most cases. The rigorously correct method given below is however just as simple.

In Fig. 1, the solid and dotted curves apply to the first cycle and a cycle of continuous operation respectively.

Then $Q\ P$ = initial motor torque in addition to friction torque, in a cycle of continuous action.

$Q'\ P'$ = final motor torque in addition to friction torque in the first cycle.

$Q'\ P'$ is known from the computations on the first cycle. $Q\ P$ bears a simple relation to it and is computed as follows.

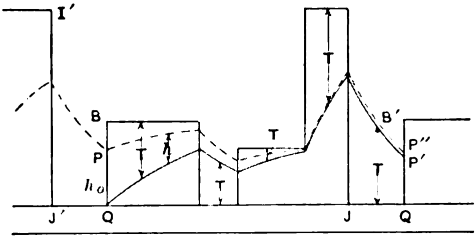

FIG. 1

It may be easily shown that the difference between the solid and dotted curves is represented by a continuous logarithmic curve whose equation is

$$\log \frac{h_0}{h} = A\ t$$

$$\text{Let } \frac{h_0}{h} \text{ for a whole cycle} = x$$

$$\text{Then } P'\ P'' = \frac{Q\ P}{x}$$

$$\text{now } Q\ P = Q'\ P''$$

Hence

$$Q\ P = Q'\ P' + P'\ P''$$

$$= Q'\ P' + \frac{Q\ P}{x}$$

$$\text{or } Q\ P = Q'\ P' \left(\frac{x}{x-1}\right)$$

That is, to compute the correction to the initial motor torque, multiply the difference in motor torque at the beginning and end of the first cycle by the ratio $\frac{x}{x-1}$

where $\log x = A\, t_c$

t_c being the time for a whole cycle.

In cases where regulating devices are used to increase the slip when a given load is exceeded, we have to deal with sudden changes in the constant A. Referring to Fig. 2, when a certain load represented by the point P is reached, the regulating device acts. Due to its time element the introduction of resistance is delayed to the point P' after which a larger value A' of the constant prevails. The total motor torque is instantaneously reduced in the ratio $\frac{C\,D}{P'D} = \frac{A}{A'}$. The torque then increases along a second curve $C\,E$ with a much slower rise, due to the greater change in speed before a given change in torque takes place.

In computing the constant A (formula 55) the torques being ordinarily expressed in pound feet and $M\,K^2$ being expressed in

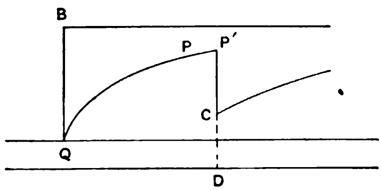

Fig. 2

pounds at one foot radius, it is advisable to introduce the factor G ($= 32.16$) directly in the formula.

In the very convenient diagram given by Mr. Gasche for computing A, M is expressed in the "gravitational" unit of mass which is equal to 32.16 pounds.

F. G. Gasche: I might give the assurance that the formulæ have been subjected to numerous applications and checked in many ways, such that the engineer may use them with some confidence.

Several years ago, the U. S. Steel Corporation inaugurated the construction of a large plant involving many features without precedent—at least in the magnitude of the several installations and the importance of the engineering problems.

It was proposed that, simultaneously, there should be complete motor driving of the rolling mills and that current should be furnished from a station involving a radical departure in the type of prime mover. There is nothing incompatible with these propositions provided the variations of frequency due to the action of the prime mover are negligibly small; but considerable

variations introduce problems of great concern when the character of mill loads in the presence of a lowering voltage is understood. Should the prime movers be guilty of erratic control the safety and commercial efficiency of the entire equipment compels the use of flywheels and other safe guards. Many of these mill drives have been equipped with exceptionally large flywheels simply as a precautionary measure. This seeming extravagance has been attended by good fortune in the way of economies in the transmission of power and in the satisfactory service of the mill equipment.

Another complication arose from the ambition to surpass all precedents in the amount and rate of displacement of the metal in many of the roll passes, thus increasing the loads which would ordinarily be imposed on the driving motor. Preceding any other consideration in the power transmission problem, it became necessary to explore in a way that unknownregion of the properties of materials which may be called the plastic state.

We have elaborately evolved mathematical theories of elasticity, and the statement of the laws applying to the region of " perfect elasticity ". Similarly, we have access to the theoretical hydro-mechanics, involving the assumption of "perfect mobility" or freedom from internal resistances. There remains to be investigated the " plastic region " promising to exact the best efforts of the physicist and mathematician before the subject is thoroughly understood and placed in the form most suitable for engineering purposes. In lieu of such assistance it becomes necessary not only to exterpolate with reference to our experimental data concerning roll train resistances, but also to investigate the "plastic region" at least, empirically, before we were in a postion to give the electrical designer the necessary load conditions within reasonable limits of error.

Possibly, a preliminary statement of the methods by which these roll-train resistances are estimated could have preceded the subject of the paper, but a subsequent statement of the case for the purpose of the Institute, if it is of sufficient interest will not suffer if suitable time is allotted to its preparation.

With regard to Mr. Dunn's observation concerning a statement in the paper, this is simply an interpretation of the formula (19) bearing in mind the value of the constant A containing MK^2 in the numerator. A zero value of MK' makes S equal to zero, or the motor does not assume the load due to the pass.

It is well within the possibilities that there is enough elasticity of the roll train connections in many cases to give an " approach " load condition as defined for Fig. 1. The allowance for such gradual assumption of the load would comp'icate the analyses beyond all requirements of practical applications unless the bar is actually a tapered ingot with little or no "draft" at the start of the pass. In this case, however, the statement to which Mr. Dunn refers does not apply when certain critical " torque-slip " relations of the motor have been established.

DISCUSSION ON "THE MODERN OIL SWITCH WITH SPECIAL REFERENCE TO SYSTEMS OF MODERATE VOLTAGE AND LARGE AMPERE CAPACITY". JEFFERSON, N. H., JUNE 28, 1910. (SEE PROCEEDINGS FOR JUNE, 1910.)

(Subject to final revision for the Transactions.)

Peter Junkersfeld: Oil switches or circuit breaking devices seem to require some further development. There is need for something different, apparently, from that which we have at the present time. My own observation is confined, principally, to what Mr. Cheyney classes as the moderate voltage, high capacity switches. This class of switches seems to be very popular. A favorite question asked of the power station man is—" Do your oil switches always open the circuit, have they ever failed to open the circuit properly?" The usual answer, perhaps given with a little hesitation, is " No, they have never failed to open the circuit." I myself have answered that question a good many times, and have been frequently tempted to add—" Yes, they have always opened the circuit, but at what cost and with what results?" The system I have in mind has at present three hundred oil switches in three different generating stations, and if the substations were included, the total would be over five hundred. The number of times that the switches were distressed was few—very few in comparison to the total number of switches. The percentage of the times when all of the oil, or a large part of the oil, was thrown out of the oil vessel, to the total number of entirely satisfactory switch openings, is also a small percentage, but it is still too large, for the reason that the amount of property involved and the number of people inconvenienced is such that the reliability, so to speak, should be increased.

There is a very urgent demand for this increase in reliability. Moreover, from the standpoint of first cost, it would seem we are perhaps getting a little bit out of balance. The very fact that occasionally a switch is perhaps, entirely wrecked, means that there is a demand and a necessity for very expensive bus-bar structures, and everything of that sort, to prevent the trouble from spreading, and this has reached a point where in many systems the cost of the various oil switches, switchboard equipments and bus-bar structures, etc., is practically equal to the generating end of a steam turbine unit.

That, as I said, from an economic viewpoint, looks as if we are going too far, but we are driven to it in order to provide the degree of reliability of service demanded. It would seem also, that in this matter of interrupting circuits, there is really no mechanical analogy, that I can think of, for the moment at least, for attempting to stop the enormous momentum in electrical circuits. Mechanically, if we stop a moving mass, we apply the brakes gradually, but with an electric circuit we attempt to stop it almost instantaneously. It would seem we should insert something in the circuit, such as has been sug-

gested, and on which work has been done in the last year, in the way of reactance. That would seem to offer a solution insofar as it would reduce the burden now placed on the oil switch. However, the progress in that direction has not been as great as we could wish, because there are many difficulties in designing and building of reactances to stand these large powers. Moreover, the experience with oil switches for very large capacities seems to have been almost entirely with one general construction, and in the present state of the art, only one thing seems to be possible for use with very large units and that is to require a somewhat larger oil switch.

Ford W. Harris: This paper is one much to be commended both on account of its being a logical array of facts from a man who knows, and on account of its general tone of fairness and moderation. Mr. Cheyney believes the oil switch is the weak link in his chain of apparatus and it is very hard to speak fairly of the weak link.

This subject of oil switches is daily assuming a greater importance due to the constantly increasing capacities of our large stations. For some years the design of oil switches has remained stationary and what was five years ago a thoroughly dependable device is now being looked upon with suspicion.

There is no question that there is not at this time on the market any oil switch which can be depended on to open heavy short circuits on powers above 10,000 kw. at 11,000 volts or below without certain manifestations of distress.

These manifestations of distress may be grouped into three classes:

1. The throwing of oil from the tanks.
2. Excessive burning of contacts.
3. Distortion of rupture of tanks due to heavy pressures generated in them.

These troubles are in themselves serious but there are two facts that in a great measure should reassure the operating engineers of the country in regard to the present status of the oil switch; these are:

1. That in no case of which we have record has an oil switch failed to clear the circuit, providing it was in normal condition upon the occurrence of short.
2. That it is only on powers above 10,000 kw., and only then if this power is concentrated at the switch, that any trouble whatever occurs.

Mr. Cheyney seems to feel that the present unlimited breaking capacity guarantee on the heavier switches is unreasonable. For some years after these switches were put in service these guarantees were absolutely correct as no complaints developed. As, however, power houses grew larger and turbine-driven generators became common the three troubles previously given developed. The manufacturing companies found themselves confronted with a growing difficulty for which they knew no

remedy. Operators in general seemed to feel that the function of the switch was to open the circuit and that this was what was guaranteed. The throwing of oil and kindred troubles are, in themselves, not incompatible with such guarantees and at the present time are an understood accompaniment of oil switch action on heavy short circuits.

This latitude of the manufacturers was not based on inertia but on the difficulty of the design problem presented. The study of short circuits is a study of calamities. The testimony of people who have seen short circuits is of little value. Practically the only remedies were in the laboratory and the study of actual short circuits produced wilfully on heavy power stations with their attendant life and property hazards. Since these large power stations are rare and since no operator will wilfully short-circuit his bus bars, except under considerable pressure, progress must of necessity be slow.

The laboratory study was undertaken and proved very illuminating, and within six months three large power stations have permitted wilful short circuits of great magnitude. The result has been a considerable mass of data which will be later incorporated into a fairly complete exposition of oil switch theory. Better yet, these tests and certain practical service tests indicate the line further development should take. It now seems perfectly possible to develop devices which will repeatedly open without injury to themselves or the circuit any current which may be generated. It is thus seen that the manufacturers are not resting idly on their present designs but are pushing forward with good prospects of success. We hope within a few months to present to the Institute a complete record of such success.

There is, however, another side of Mr. Cheyney's paper. There are, of course, varying degrees of excellence in the oil switches now on the market. The present designs are pretty much standardized along certain fundamental lines.

These fundamentals of design are pretty generally observed by all oil switch manufacturers in this country and abroad. The designers of the switch on which Mr. Cheyney's paper was based evidently aimed to produce a switch of great rupturing capacity and have adopted a design that necessarily violates some of these fundamentals. Some of Mr. Cheyney's trouble seems to be due to this. It seems to me that a statement of these fundamentals and a discussion of their bearing on the problem may not be out of place. I would, therefore, submit that in any high-tension oil switch the following main principles should be incorporated.

1. There should be no exposed live metal parts. Switches in which oil pots are alive even if they are enclosed in a cell with a door form a very dangerous life hazard and a source from which dangerous arcs start.

2. Switches should be so arranged that gravity will tend to

open the switch so that if mechanism is in the open position the switch will be open. The falling closed or staying closed of a switch which should be open is fundamentally wrong. The breakage of mechanism at any one of several points on such a switch would result in life and property hazards that cannot be ignored.

3. An oil switch should have all breaks under oil. In the heavier capacity switches of the type in question an auxiliary main brush is used to finally close the circuit in parallel with oil break. The destruction of contacts in oil will throw the whole duty on the air break with a probable total destruction of switch and a bad oil fire.

4. Mechanisms to be permanent and reliable should be self-contained. The fastening of one part of mechanism on top of brick cell and supporting the remainder on porcelain insulators and expecting permanent alignment under the enormous stresses of short circuits is bad practice which should be avoided. Each pole should be operative outside of the structure and permanently aligned to some substantial frame at the factory of its maker.

5. Solenoid operation rather than motor operation. As one who has designed good, bad and indifferent switches, both motor and solenoid operated, I cannot too strongly urge the claims of the simpler cheaper and permanent solenoid as against the motor. What is needed in any switch is a sure short and powerful stroke and to obtain this by gearing down a small torque at high speed into a compressed spring must result in a complicated mechanism. These mechanisms and the motor itself require frequent inspection and adjustment. The trouble mentioned by Mr. Cheyney as "pumping" is a very serious one. As I understand it, this means that in opening or closing, the switch fails to stop at the appointed place but throws in or out violently several times. The effect on a circuit of such an action cannot be good, and the effect of throwing a short circuit alternately off and on generators must be very bad. Such action on a solenoid operated switch is obviously impossible. The 18 cases mentioned by Mr. Cheyney of such "pumping" were luckily all caught by his inspection.

In general it may be said that Mr. Cheyney's inspection as detailed by him is very thorough and is an exceptional condition. It is reasonably certain that such inspection cannot be expected except in a very efficiently managed station and that the table of troubles made up by Mr. Cheyney represent the very best of operating conditions. In thus outlining his inspection he has indicated what one operator is willing to do to keep apparatus in first-class condition and while such exceptional care cannot regularly be expected, an improvement in this particular can profitably be made in many stations.

C. W. Stone: On the first page of Mr. Cheyney's paper he says "that it is probable that we could get the manufacturers

to construct switches to open safely short circuits under the worst possible conditions in systems of unlimited kilowatt capacities, the only limiting condition, of course, being that the consumer be willing to pay for it." I rather doubt this possibility. I do not believe we can get switches that will open under the worst possible conditions, that is, instantaneously. If Mr. Cheyney means a type of switch which opens slowly after the disturbance is largely over, then I would agree that it is possible.

Mr. Cheyney says that a large volume of oil greatly increases the factor of safety. My experience has been the other way—a large body of oil does not increase the factor of safety, unless we assume the same type of switches in both cases. Take a switch mechanism similar to the type H switch; if these oil pots contained a larger body of oil, there is no doubt but the effectiveness of the switches is increased, but if we compare this type of switch with any other standard plunger type of switch, and use a larger body of oil, the H switch will open many times the capacity. Even in the larger high voltage switches, such as the 110,000-volt switches, a large single plunger type switch will in all probability open a heavier short circuit than a large square, or oval, or round tank similar to the other types of switches in use on the Pacific coast.

Another objection to the large amount of oil is if there are one hundred and fifty switches in a station, it is not desirable to have so much oil in a station on account of increased fire risk.

Mr. Cheyney mentions the enormous growth in the transmission systems, and therefore the necessity for larger switches. Why, if we limit the capacity of our system, or the sections of our system, and install reactance, such as has been proposed in a number of cases, and such as is being done, or at least being projected, is it necessary to have larger switches? I think the reactance will tend to limit possible damage in case of short circuits, and possible disturbances of the system; that is, disturbances will not grow to such an extent if the reactances are used. Mr. Cheyney mentions that later on, and I agree with him fully.

I think the object of the oil switch is to clear the circuit from trouble. We can keep the trouble on a little longer, and thereby save the switch. Is it not preferable to destroy the switch, if we can clear the circuit, and according to all the experience I have had the switch always opens the circuit. Suppose we cut off the damage from the switch, will not that damage something else on the system which will cost more to replace?

Mr. Cheyney says "Choke coils to limit the generating capacity in one section of the bus to a value of perhaps 20,000 kw., or a capacity slightly above that quoted when the switch was disabled, would seem hardly practical." There is no doubt but that this is a very difficult problem to solve, but I do not think there is any reason to suppose that in a few months that problem will not be solved satisfactorily.

Mr. Cheyney also says that the knife switch in series should be placed in a compartment below the oil switch. I know this is the practice in a number of cases, but I do not agree with it. I think it is the worst place you could choose. The object of the knife switch is to cut the oil switch out of circuit, when the oil switch is to be inspected. If you have immediately below the oil switch some live terminals, why are you not increasing the risk of the operator when he tries to make an inspection of the oil switch, as he must necessarily work within three or four inches of the live circuit? I think that is undesirable. I have also felt that the knife switch below the oil switch is dangerous. unless locked in position, because in bad short circuits the knife switch has been thrown open, before the oil switch could act, due to the violence of the short circuit.

Mr. Cheyney mentions the effect on the system due to heavy short circuits, that is, interfering with the frequency or the voltage of the system. I think if we use reactances we would limit that effect and provide for such disturbances.

I note that Mr. Harris objects to exposed metal. I think it is a very good plan to cover up all the metal you can, but if you do it at the sacrifice of something else I think you had better expose the metal. My experience is the safest switch is the switch in which the metal is exposed and surrounded by a brick compartment. Then any trouble which may occur will be confined to that brick compartment. The mere fact of putting insulation around the oil pot simply tends to increase the fire hazard.

My experience is not exactly the same as Mr. Harris' in regard to the "pumping" of oil switches. I have seen a good deal of trouble in several cases, due to severe pumping, with solenoid-operated switches. I have seen these switches pump just as much as the motor operated switches. My experience is that the solenoid operated mechanism is more costly and complicated, and less liable to operate in case of low voltage on the operating circuit than the motor-operated mechanism. A motor-operated mechanism can be designed so that the opening of the circuit is independent of the motor, whether the motor moves or not. I think this type of switch will usually clear the trouble better than any type of solenoid switch I have ever seen.

D. B. Rushmore: The functions to be performed by oil switches vary greatly, and the resultant troubles in their operation depend to a large extent upon the particular service for which they are used. Small hand-operated switches are often opened and closed but a few times during the twenty-four hours. Large high-tension switches are as a rule very seldom operated. Other switches which may be used for intermittent motor service in connection with control apparatus may operate at intervals of a few seconds. We thus have a wide field of application and no one switch can be expected to be equally satisfactory under all the various conditions of operation.

During the last few years there has been a very rapid increase in the generating capacity tied together in the large Edison systems, and these present one of the most difficult problems of switching.

As a criterion regarding the satisfaction which a piece of electrical apparatus may have been giving, nothing is better than a study of the facts in connection with its use. It is a matter of record that certain types of oil switches in use have had complaints concerning their operation which amounted to a fraction of one per cent, and a piece of apparatus with such a record can be called highly satisfactory.

Mr. Cheyney's paper should not in any way be taken as an attack on oil switches. Very seldom is a record made of good, successful performance. It is only in the failures and disturbances that we are particularly interested, for it is desirable that our attention be concentrated upon these. Generators fail, transformers blow up, and every piece of electrical apparatus is liable to disturbance of some kind.

Of late a great deal of experimenting has been done with oil switches, the results of which are embodied in apparatus rather than in a history of experimental work. The horizontal switch of which Mr. Cheyney speaks is used to a certain extent in California. Before being manufactured there, it was brought out in the East by one of the smaller electrical companies. It has, however, certain limitations, and under some conditions affects unfavorably the limitations of power house design. Up to the present its use has not become very general.

Certain types of switches before they have been put on the market have been subjected to endurance tests in opening hundreds of short-circuits in rapid succession.

High-voltage switches are in an altogether different class. The difficult problem before operating and manufacturing companies is the one of developing switches for use on circuits where very large capacity of generating apparatus is installed, and especially where automatic relays are used with the switches.

In high-tension switches the difficulty is largely one of insulation. For use with the highest voltages, it is not an easy one to solve, and in switches recently developed where the specifications called for a high-potential test of 300,000 volts a considerable amount of experimental work was necessitated in connection with the development of such apparatus, the results of which have, however, been entirely satisfactory.

On the market to-day may be found a considerable number of what might be called "home-made" high tension switches, and these are to some extent used on the transmission systems on the Pacific Coast. At least one large power house has been destroyed as the result of the use of these switches. With them automatic attachments are but seldom employed, and they may be more properly considered as disconnecting oil switches, rather than as performing the functions for which a switch is usually installed.

On many systems the capacity of generating apparatus has increased far beyond what it was when some of the switches were installed. The throwing of oil in the switch is a safety feature, and is not an indication of the failure of the switch. Almost never is it reported that the switch fails to open the circuit.

New types of switch will be developed in the future, and with harmonious working between the operating and manufacturing companies, the new problems which constantly present themselves with the growth of systems and the development of the art will be given the same careful study which they have received in the past and will meet with the same satisfactory solutions.

C. P. Steinmetz: Before criticising the oil switch, let us see what it has done. Most engineers will agree that the operation of our present very large power stations has become possible only by the development of the oil switch. At the same time most manufacturing as well as operating engineers, will concede that still further improvements may be possible in the oil switch. Let us see what the problem is which we have to meet.

I do not agree with Mr. Harris' statement of the fundamental principles of the oil switch. It rather appeared to me that the requirements propounded in his discussion are not fundamental principles, but constructive details, mostly of a mechanical nature.

To still further improve the operation of the oil switch there are two ways; first, reduce the power which the oil switch has to control; second, improve the oil switch. The former is the problem of which the engineers have heard a great deal in the last year or two, because it is a problem which has to be worked out by the operating engineers, and manufacturers together—it means cutting the system into sections, by putting in reactance, so as to limit the maximum power which can be developed at any place. That is one of the first things which has to be done, because no oil switch can ever be designed, nor any other apparatus, to control unlimited power.

The second problem is to improve the oil switch. Though we do not hear so much about it, it is being recognized and worked out as industriously, if not more so, than the other problem.

In the paper we read about the desirability of using air pressure. This matter has been studied very thoroughly, pressure gauges have been put on the switch at various points to measure the pressure produced by the operation of the switch, by the energy of the arc which produces a rapid evolution of gas, and so brings to bear upon the break the pressure caused by the momentum of the oil, pressures which are far greater than any possible air pressure. After all, what the oil switch does, is to break the arc under the enormous pressure created by the momentum of the oil, which is to be pushed out of the way of the

arc, and that pressure exerted is far greater than any pressure which you could maintain over the oil.

The action of artificially produced pressure has also been studied. I recall some very interesting experiments which were made by operating an oil switch under pressure. We had a pressure gauge on, the needle of which went off the scale at 2,000 pounds, and immediately afterwards the top of the oil switch, together with the oil—it was a heavy steel tank of bomb construction—went up into the air.

The oscillograph is a valuable assistant in the study of the oil switch, and many thousands of oscillograms have been taken in studying the performance of the oil switch, and in studying the performance of the circuits controlled by it, and we know a great deal about it, very much more than usually supposed, though we do not know as much as we would like to know.

You will realize the importance of the problem before you when you think what the oil switch has to do. Consider a system like that of the Commonwealth Edison Company, in Chicago, with a short circuit at the bus bars. The instantaneous power generated is between 6,000,000 and 8,000,000 kw. Now stand at the foot of the Horse-shoe Falls at Niagara and think of the problem involved in instantly stopping its power, and there you have the problem of the oil switch on a high power system. It is not an easy problem, and it is difficult to realize what we have to deal with. It is not the few hundred thousand kw. of the generators with which we have to deal, but the many times larger momentary power.

Now, what is the destructive effect on the oil switch? It is energy, but energy is power times time, and this means you can reduce the destructive energy by shortening the time. On the other hand stands the well established fact that the opening of the enormous power in too rapid time, destroys the system back of the oil switch. If you open the circuit too rapidly, the oil switch may be saved, but you destroy the cables and everything else. If you open it too slowly, you blow the oil switch to pieces by the energy produced there. Between these extremes you have to compromise.

The oscillograph records give us information how far we can reduce the energy of the oil switch by increasing the rapidity of the opening, without endangering the system, and that is work on which we are engaged. The fundamental principle of oil switch design thus is to open the switch with the minimum energy production in it, but at a rate slow enough not to produce destructive effects in the system controlled by the oil switch.

I have spoken of the oscillograph, and incidentally I may correct a misconception. It has frequently been believed that the oil switch opens the circuit at the moment of minimum stored energy, that is at the moment when the potential energy stored as magnetic and as electrostatic energy is a minimum. However, the oscillograph records, as far as I have been able to study

them, point to the fact that, irrespective of the stored energy in the system, the oil switch opens at the zero value of current. For instance, in the charging current of a 100,000-volt transmission line, of say 150 to 180 miles, we have an electrostatic energy much larger than the electromagnetic energy, still the oil switch breaks at zero current, which is practically coincident with maximum voltage; that is, with maximum stored energy.

That is fortunate, because the cause of destructive effects is not the electrostatic energy of the system, but the electromagnetic energy. The electrostatic energy is limited by the voltage. We know, no matter what oscillation is produced by the electrostatic energy, the voltage can never more than double. It is less than double voltage, and since the double voltage is momentary, any insulation which can continuously stand normal voltage can momentarily stand double voltage. But in the rupture of the current the magnetic energy is unlimited; it can be anything up to the magnetic energy of the short circuit current, which is many times greater, especially in these high power systems, than any static energy, but that energy, fortunately, is not destructive in the oil switch, because the oil switch opens at the zero of current and thus zero of magnetic energy. It is very interesting to observe this on high voltage systems.

As I stated, there is sufficient evidence available to-day in oscillograph records, and it is being worked out at the present time, but that work is necessarily slow.

W. I. Donshea: Mr. Cheyney refers to a number of instances of the oil switch, of the type he has under consideration, successfully doing the work for which it was designed, and he mentions specifically one switch which opened 25 consecutive short circuits within a space of one-half hour, and also two similar switches which in three years opened several hundred short circuits without a change of oil. But he says, "The enormous growth of connected load and, at the same time, the adoption of the steam turbine as a prime mover, have brought about conditions unforseen; and not only has the ability of modern switch construction to safely care for the new conditions been questioned, but experimental evidence would lead to the conclusion that either a new form of switch is urgently needed, or else a marked change in switchboard construction and station operation."

The speaker is of the opinion that this view is not warranted, and he would cite the experience of a company which has in use about six hundred and fifty of these switches, of which four hundred are located in the two power houses and the remaining two hundred and fifty in the twenty-six annex stations. The rated generating capacity of the two power houses is 160,000 kw., (all connected to one bus) of which 121,000 kw. are in steam turbine prime movers, that is of the type which the author mentions as imposing exceptionally severe duty on the switching

apparatus. These switches are giving satisfactory service, and they have not failed in a single instance to disconnect the most severe short circuit to which the system has been subjected. This experience indicates that the present conditions were foreseen and that both the manufacturers and the operating companies were keenly appreciative of the importance of the interests they controlled, and had already designed on the one side and accepted on the other, apparatus which is capable of preserving both safety of equipment and continuity of service.

The author also refers to the need of overhauling the switches, examining contacts and replacing the oil and says, "This whole operation involves a period of at least two hours, and if spare feeders are not available may lead to considerable annoyance, while in any case it may involve a temporary disablement of a large and important investment in apparatus." But it is not customary to install a system of the magnitude suggested by the author without an ample surplus of capacity in feeders as well as in the other parts of the equipment. It is universal practice with such large companies to keep in service a sufficient number of generators, each with so high an overload capacity that any one of them may be disconnected without materially affecting the system voltage; a sufficient number of feeders (laid through duplicate routes) to the distributing stations, and connected there to machines, which, like the generators in the power houses, are in number and overload capacity ample to maintain the voltage of the system. On this point I might quote from Mr. W. F. Wells in a discussion of a similar subject in May, 1905: "In general sufficient equipment is installed and operated to render it possible at all times to disconnect instantly any individual or group unit, without interfering with the service. As the number of units increases, the proportion of investment in emergency or spare equipment diminishes and soon becomes of relatively minor importance. The interest and depreciation charges on account of this spare equipment are partly offset by the greater flexibility in operating and the decreased transmission losses." But unquestionably there is no large company such as contemplated by the author which would not recognize the principles of insurance as applied to reserve equipment as well as to fire and other hazards.

The author treats interestingly the subject of oil which has been exposed to severe arcing, but the results of tests which he reports are so variable that they seem to commend the practice of discarding all oil which has once been subjected to the strain of dissipating a severe arc.

In the concluding paragraphs the author says, "Constant vigilance is necessary." It is perfectly true that frequent inspection of all apparatus is both prudent and profitable. In the two power houses mentioned an inspector makes a tour through the switch rooms once an hour for the purpose of examining all parts which are exposed to view, and of locating excessive heat

in any switch enclosure. In addition to this, all switches are cleaned once a week, and they are dismantled and reassembled once a year. Whenever a switch opens under load the oil is removed, (and this oil is either thrown away or used for other purposes) the contacts are overhauled, the entire switch thoroughly examined and new oil is put in. In short, every effort is made to maintain the entire switch equipment in a condition which is at all times as good as new.

What I have said about the existing switch must not be taken as indicating that I feel it is perfect or that there is nothing better to come, but it is a good switch; it is not a one man's idea, but as a previous speaker indicated it is a resultant of the policy of coöperation and consultation which has always existed between all the manufacturing and the operating companies. To use a homely expression, "both sides have been onto the job."

V. Karapetoff: It was interesting to note in this discussion that a more rational method for opening circuits behind a large amount of power is being discussed, and several speakers have mentioned the use of reactance coils. I should like to know more in detail the actual connections when reactance coils are used, that is to say whether such coils are connected between separate feeders, so as to limit the interchange of energy, or if they are permanently in series with each individual feeder; also, if such reactance coils must contain no iron? I should like also to inquire if the scheme has been tried of having series reactance coils normally short-circuited by the oil switch and automatically introduced into the system by the opening of the switch?

G. F. Sever: I ask Mr. Cheyney why he uses the value of 50 in determining the amperes per phase? That is not quite clear to me.

A. R. Cheyney: This paper seems to have been productive of a very valuable discussion. First of all I want to disclaim all intention of seriously criticising any particular switch, merely desiring in my paper to show the actual results which we have experienced with oil switches in actual service, and hoping that in the discussion new points with regard to design and operation might be uncovered.

In answer to Prof. Sever's question, I would state that the figure 50 used in calculation of short circuit current of alternators is a figure frequently given by which we may multiply the normal full load current in amperes in order to obtain the instantaneous value of the short circuit current.

In reply to Mr. Harris, I would state that in connection with the table of inspection from which he quotes, the examples of pumping did not occur in any instance with a switch in service. There was, therefore, no pumping of machine or feeder switches on short circuit with machines out of step.

I fully agree with Mr. Stone with regard to large and small volumes of oil in a switch, as he states a rupturing capacity of a switch with a larger cylinder and a larger amount of oil present

is considerably greater than that of a switch with a small cylinder. The best means of obtaining a maximum rupturing capacity in a switch was one of the main points which I intended to cover in the paper.

The knife switches used in connection with the oil switch should of course, be separated from the switch connection proper by a fire-proof barrier, the point in this connection I wished to bring out being that it is quite important that the man working on switches should be able to see for himself the switch which absolutely protects him from possible injury. He can then rest assured that by no chance can the knife switch be closed without his knowledge.

Uncertainties with regard to the real necessity for reactances are being rapidly cleared up so that while a year ago we talked of reactances being necessary between two stations of 100,000 kw. capacity each, and possibly in connection with sub-dividing the bus-bar of a 100,000-kw. plant, now we are considering the proposition of reactances being absolutely necessary if we wish to protect the switch itself between sections of a generating station each of 20,000 kw. or under.

Professor Karapetoff has asked what wiring connections are used in installing the reactances. These are installed in several ways in accordance with the conditions confronting the designer of the plant. In the bus bar they would, of course, be directly in series with each bus conductor between sections. When installed on generating units they are sometimes connected directly in series with each conductor at the generator terminals and possibly also in connection with the grounded neutral. The chance of resonance troubles due to this series connection, particularly in large underground systems, has not yet been very fully discussed before the Institute to the best of my knowledge.

We are thus face to face with the following solutions:—First, install at very frequent intervals heavy reactances which will in all cases divide the station into sections of 20,000 kw. each as a maximum. Second, use the present switches without reactance and take the chance of serious damage to same and possibly a simultaneous interruption of service from the dropping out of step of a considerable part of the synchronous machinery. Third, the development of a more powerful switch. The latter solution seems to me so very desirable that I should hesitate to give up at this time all hope of its possible accomplishment.

E. M. Hewlett (by letter) In reviewing Mr. Cheyney's paper, the writer is much impressed with the excellent performance of the oil switches. It is gratifying to note that in all cases in service the switch opened the circuit on overloads and short-circuits and that the tests were thorough enough to develop practically all the faults during the test period. Considering that there were nearly 100 switches involved, it would seem that the oil was changed on an average of a little less than once a year per switch and less than two adjustments were required per switch per year.

Regarding simplicity of design, this point cannot be too strongly emphasized. It must, however, be remembered that the operating conditions imposed on the oil switches contribute in a large measure to the design. The switches are called for to be remote control, capable of being operated at some distance from the switchboard, automatic, sometimes with time limit and indicating devices to indicate the position of the switch, and many other extra functions. It should be appreciated that

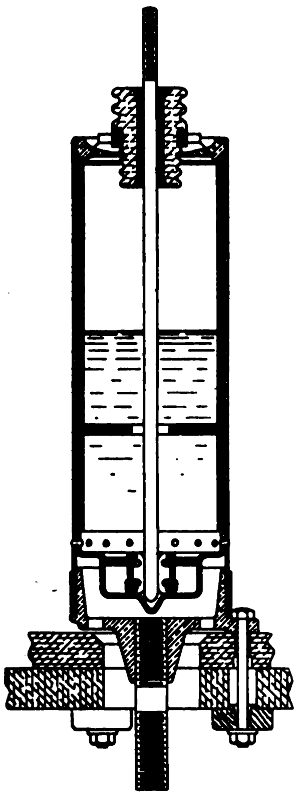

FIG. 1

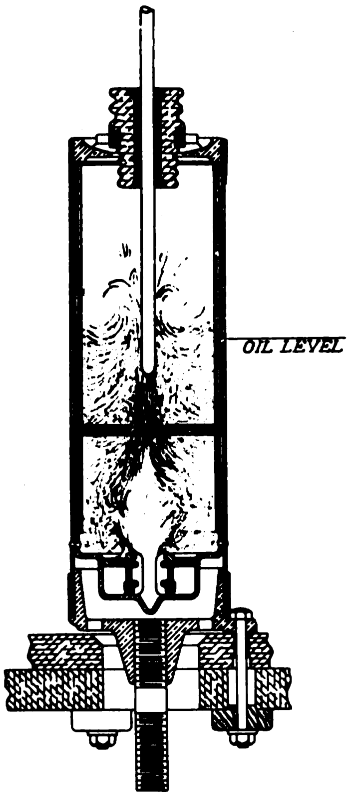

FIG. 2

these extra conditions and requirements have been demanded when considering the complexity of the switching device.

In order to discuss the oil switch situation it seems best to separate the subject into the mechanical and the electrical operation. The mechanical operation may be remote control by the means of compressed air, solenoids, motors, rods and bell cranks, according to the requirements of the case, using the best method fitted for the conditions.

The H form of switch with its motor driven mechanisms is designed for remote control operation, so that a large number of generator and feeder circuits can be gathered together where they can be conveniently observed and controlled by an attendant.

The three-phase H oil switch in its present form consists of six steel oil vessels, eight inches in diameter, with casting at the top supporting porcelain bushings through which the contact rods may operate. These rods, or arcing tips, make contact with a special four-segment contact under spring tension located in the bottom of the oil vessel, and are submerged in transil oil which has a high voltage breakdown point and will not easily carbonize. The depth of oil over the contacts in each vessel is eight to 10 inches, approximating two to three gallons per vessel. At the bottom of the oil vessel is a heavy clamp which serves as a mechanical support and at the same time provides an electrical circuit. For capacities over 300 amperes brushes are attached to the crosshead, which carry the main load current but do not break any load. Two oil vessels with contacts are used in each cell, thereby giving a double break for each of the three phases.

The high rupturing capacity of the H form of switch is due to the baffle plate or pressure chamber construction; Fig. (1) *i.e.*, the arc is sprung in the pressure chamber at the lower part of the switch and the gas generated by the arc expands and forces the oil under pressure through the same aperture that the arc is drawn through as it follows the contact rod (Fig. 2). This stream of oil under pressure driven into and across the path of the arc makes a very effective means of opening electrical circuits of large capacity with a small quantity of oil, the oil receptacle and baffle plates being made to withstand the pressures.

Owing to the flexibility of this construction it is permissible where large amounts of power are to be controlled to further isolate by means of separate compartments for each oil vessel with its individual break. As an extra insurance it is possible to install the mechanism above this layout, thereby affording protection to the attendant when adjusting neighboring switches, at the same time preventing the possible spreading of high power arcs to the low potential or control circuits.

From tests and experience it does not seem advisable to go to the extreme of placing the main contacts under oil, as it introduces serious complications.

The K form of switch, in which two or more arcs are sprung in one oil vessel, is used in switching moderate amounts of power and can be designed for ordinary cases until the pressure developed and the amount of oil required make it necessary to consider other design. This K form of switch is top connected and permits a very flexible bus bar layout. A switch of this nature is limited in its rupturing capacity due to its rectangular

or oval tank, and the difficulty of confining the pressure and directing the oil in such a receptacle.

Regarding Mr. Cheney's statement on oil switch improvement, a high rupturing capacity H switch has been designed for stations with 20,000 kw. turbo-generator units.

Regarding the possibilities of switching apparatus, oil switches can be made to handle any generator or capacity desired; it being a question of space limitations, expenses and a knowledge of the circuit characteristics.

With very large generating capacities a switch designed to open the circuit instantaneously might be so large in dimensions that it would be prohibitive as a station device and the better plan seems, in order to keep oil switches of reasonable dimensions and moderate expense, to limit the conditions by sectionalized busses, reactances, time limiting devices, etc.

Discussion on "Headlight Tests." Jefferson, N. H., June 28, 1910. (See Proceedings for July, 1910.)

(Subject to final revision for the Transactions.)

C. A. B. Halvorson, Jr.: There are a few points to which I would call attention.

So far as I am able to judge, the benefit to be derived from the use of a powerful headlight is the feeling of security and confidence given to the engineer. With the track ahead in darkness or poorly illuminated, his nerves may be kept constantly " on edge " making him liable to blunders. Or, on the other hand, he may become reckless and simply trust to luck. I base my opinion on experience gained under actual operating conditions and from talks with engineers.

No reference is made to tests on wet or foggy nights. On such nights the ground and the sleepers as well as all other unpainted wooden objects along side the track appear black from absorption of water. Or, in case of a heavy fog bank this will appear as a solid illuminated wall shutting out the view of anything ahead.

There is another point in the conclusions to which I wish to refer. It is stated that " A powerful opposing headlight adjacent to block signals so obscures the latter as to make it difficult to read them correctly at distances exceeding 1,000 ft." It seems to me that this would be easily overcome by drawing up a set of rules governing the use of headlights. This has been done on some roads. When two approaching trains come within view of one another, the luminous arc of both headlights are extinguished and the less powerful incandescent lamps lighted. This practice obviates the difficulties mentioned.

Instead of advocating less powerful headlights, I would recommend increasing the efficiency by raising the current to 7 amperes. The ordinary luminous headlight as operated to-day is run at 4 amperes, consuming about 500 watts at the terminals. Improvement in the accuracy of the mirrors is also needed.

It was my pleasure to make a test on the D. & H. line between Albany and Whitehall, using a locomotive headlight operating with a 7-ampere magnetite arc, and we could easily discern persons walking on the track at a distance of 1700 ft. A combination of mirrors was used in this headlight, consisting of a large parabolic metallic mirror and a 9-in. Mangin mirror. The results obtained with this headlight were very fine, indeed.

With reference to reversing the polarity of the arc in order to dim the light, I would suggest that an ordinary incandescent lamp would probably give much better results than a reversed arc. Such a lamp placed out of focus of the mirror as an auxiliary to the luminous arc seems to me the best solution of the glare trouble.

Most of you are probably familiar with the luminous arc. It is a very long arc and the light is given from a core which is intensely bright. When a Mangin mirror is used, the light

projected is practically an image of the arc. The beam, therefore, will be of small width, the principal extension being in a vertical plane. By using small diameter electrodes it should be possible to confine the light to the space between the rails. and this has actually been accomplished. In this way all trouble on account of reflection from roundels, etc., can be eliminated.

The third conclusion states that " The lens type of projector has a higher multiplying factor than the reflector type, other things being equal ". This may be true when the comparison is made with ordinary metallic mirrors. Comparing the lens form with the Mangin mirror form of headlight I doubt that the statement holds good. I would like to know whether Professor Harding has made any tests along these lines.

John B. Taylor: Some data as to the make-up of the observing committee seems desirable; first, whether the same eleven men were interested in all the tests, and, second, whether they were trained railroad men, and if not, what was their particular occupation in life. I understand tests will show about one man out of every two dozen to be color blind, so that we should know whether all these men went through a color blind examination, before they were given a position of this committee. I would ask also whether the lower values of distances given for recognizing the signals and obstructions were usually determined by one or two exceptional men, or whether they are fair low average values?

George H. Stickney: The brief inspection which I have made of the paper seems to indicate that, under existing conditions of signals, etc., the use of high power headlights was not found beneficial, inasmuch as they interferred with the reading of signals.

The purpose of the headlight is two-fold, namely to assist the engineer in seeing ahead, and to warn people of the approach of the train. With low-power headlights the former function is practically lost, and in foggy weather the range of warning is quite limited. For these purposes therefore there is unquestionably a demand for powerful headlights.

The objection to their use apparently relates entirely to the reading of signals. In regard to this point there seem to be a number of possibilities of eliminating or reducing such interference. For example, the headlight beam may be directed very slightly downward so as to fall below the eyes of the engineer of an approaching locomotive. At the same time the signals could be placed above the range of the beam. Very accurate control of a light beam is obtained, for instance, in a stereopticon projector, so that it would seem possible to produce this effect without limiting the range of illumination along the track.

Harry Barker: The opening paragraph of the paper states that the Indiana Railroad Commission was instructed to investigate the rules regarding the compulsory use of more power-

ful headlights on steam locomotives operating in the State of Indiana. I would ask if Professor Harding could inform us as to the ruling of the Commission? I understand, that in spite of Professor Benjamin's report, mentioned later in Professor Harding's paper, and in spite of the somewhat adverse findings of the special sub-commission, or of the individuals of the Railroad Commission, the Commission has, nevertheless, ordered that high-power lamps be used. If that is so, it might be interesting to know some of the qualifications of these instructions.

C. P. Steinmetz: This paper is very interesting, though some of the results at first appear unexpected; *i.e.*, the result that the more powerful headlight is inferior, in certain respects, by making the signals less distinguishable. If we apply that reasoning still further, it would follow that the best way would be to have no headlight at all, because then you would see the signals best.

Now, on the other hand, if we have a headlight, and need a headlight, it appears reasonable to expect that the more powerful the headlight is, the further distance we can see obstructions or other defects of the roadbed, and the further distance one can be seen; therefore, the most powerful headlight would be the most satisfactory one, except as regards the signals. It would be interesting to investigate whether this objection regarding signals could not be overcome by applying the same remedy. If we need a high-power headlight, why not also use higher powered signal lights to make the two again comparable with each other, and at the same time apply this remedy which has been suggested here, that is, to control the beam of the headlight so as not to throw it directly on the signals.

We all know if we send a powerful beam of a searchlight against a small and low intensity light, we do not see the latter light very well, and we do not need any test to tell us this. Besides, it appears to me that the case of looking at signal lights against an opposing headlight is rather an exceptional case. If there is another train coming, with a powerful light, either we must be sure of our signals, or must slow down. I do not think it is generally the case that two locomotives, when not certain of their signals, will approach each other at full speed. We may turn the headlight away, or turn it out, or do anything else, or may slow down, and if we slow down even for a distance of a few hundred yards, that distance will be sufficient to enable us to avoid any obstruction.

I believe the question requires further consideration and investigation before we can accept the theory that the headlight of a train can be too powerful.

Charles F. Scott: One use of the headlight referred to a few moments ago is to give a warning of approaching trains to people not connected with the railroad. In some cases, the headlight can be seen long before the approach of the car can be heard.

As electric trains come into use, and do not have smoke to

indicate their presence at a long distance, the headlight at night gives a very fair indication of the position of distant trains, which would be of very great use on single track roads.

With regard to seeing of signals, the suggestion is made that a different form of signal, a position signal, might be advantageous instead of a colored signal. A position signal might be seen very clearly, irrespective of the color of the signal.

With regard to operation at full speed, and in connection with a point made by the last speaker, namely, the suggestion that if there is an approaching train with a powerful headlight, it is well to slow down, it may be remarked that there are cases, such as on double track roads, or four track roads, with block signals placed at frequent intervals, in which trains do run in opposite directions at high speeds, with signals at frequent intervals where the approaching headlights may dazzle the eyes of the engineer.

All these little points show the intricacy of the problem, and I think the paper, as a whole, brings out in a very emphatic way the need for the kind of investigation and scientific analysis which has been given to a problem of this kind. I presume that practically all of us, would have said off hand that the arc light would be an excellent headlight and its general adoption desirable. But these various indirect points, the dazzling of the eye of the approaching engineer, the obscuring of signals, the changing of the colors of signals by reflected light, all of which indicate the importance of a thorough scientific investigation of the subject, show the high value of papers such as the one we have just had.

George A. Hoadley: There is just one point not touched on, and that is this; the very great difficulty there is of forming any judgment, within satisfactory bounds of accuracy, as to the distance of a powerful headlight. To a person on the track, it is impossible to tell if the headlight is three hundred yards away, or one hundred feet, so it seems to me the headlight which gives a perfectly parallel beam of light, that does not strike the track, is an objectionable form of headlight. If the light strikes the track, the observer has an opportunity to determine the distance of the headlight from the point at which he is standing.

Harry P. Wood: I would ask Professor Harding if he made any test to determine the proper height of a headlight above the track? In the electric road the headlight is close to the track, and I understand, as regards engineers in the cab of a locomotive, there is a difference of opinion as to whether the headlight should be at the center of the smoke-box or above the smoke-box. I think the lower headlight will be better than the headlight which is placed higher up, as in the lower position the beam of light will not be entirely in the direction of the engineer's vision.

J. C. Lincoln: I should like to know if Professor Harding made any test to determine whether the green reflection, which

seemed to throw some doubt on the signals, could be gotten rid of by the suggestion just made, of throwing the light on the truck, so that no direct light from the headlight would strike the signal whatever?

C. Francis Harding: This subject of compulsory use of more powerful headlights on railroads, especially on steam railroads, is a comparatively live one in the middle west at the present time. Because of the fact that it has been given especial attention in that section of the country, and for the reason that it has been thought that engineers in general and especially those connected with steam railroad work, would be interested in this discussion, it is presented in this form to-day.

Referring to the question of the feeling of the engineer on the engine, I would say that all of the signal engineers with whom I have talked, and also many of the older steam locomotive engineers, have expressed themselves emphatically in favor of the old type of headlight, so far as security is concerned, and in fact some of the older engineers who made up the Committee of the Brotherhood of Locomotive Engineers, who first proposed this bill to the Indiana Legislature, told me that they could run equally well without any headlight at all, that they did not depend upon the aid of a headlight for determining their location or determining the schedule time in passing various objects —that they had markers of their own along the track, such as houses, gate openings, bridges, etc., and that they could easily get this information without any headlight, in a manner that was entirely satisfactory to them.

Regarding the question of fogs, I will say that some of the night tests at the University were carried out during foggy nights, and when we have a bank of fog in front of the headlight, looking parallel with the track, we have in front of us practically an opaque screen, brilliantly lighted, but very near the headlight, through which it is almost impossible to see, and that opaque screen seems to be more of a barrier, the greater the intensity of the light.

With regard to the matter of extinguishing or reducing the intensity of the lights in approaching other locomotives, I will say that, of course, that practice is used with interurban cars to a large extent, and it is probably a practical suggestion in the case of a good many steam roads, but an objection to that has been brought up by one of the signal engineers of a road entering Chicago. He says that an engineer on a train entering Chicago at the schedule speed has to read a signal every fifty-five seconds, and it would be impossible to diminish the intensity of the light, momentarily, while reading signals—it would therefore be necessary to reduce the light during the entire run.

Regarding the picking up of objects other than those considered in this test—the various observers on the road test in going from Indianapolis out to the scene of the test, were able by counting the poles to pick up overhead bridges, fences, etc.,

at a maximum distance of a quarter of a mile. All of these objects were white, or nearly so, and it was remarkable to note the difference in distance in picking up objects which were light and those which were dark. It happened that all the objects used in the test were dark, or nearly black, and it was surprising to all observers to note the results shown in the tests, that we could run down within a very few hundred feet of a black object and not detect it even with a powerful headlight.

I will say that the Mangin mirror type of reflector for headlights was not tested, and the statement in the conclusion of the paper simply applies to the particular lights tested, one with a lens and the other with a reflector, the other features of the light being identical.

Regarding the make-up of the observing committee, I will say that the Railroad Commission was represented by three men, the railroads of the State by three men, the University by three men, and two other parties selected at random. The men were not tested for color blindness, but the comparisons of the results of the different individual papers recorded independently would seem to show that no such condition existed in the eleven observers selected—that none of the members of the observing committee were color blind. I think an inspection of the original data would convince one of that fact. The readings at lower values, *i.e.*, shorter distances, seem to be pretty general, that is, not always noted by the same individuals with an opposing electric headlight while with an opposing oil headlight there is considerable similarity in observations of a single individual with respect to distance.

With regard to the matter of focussing below signals, or opposing engineers, it would seem to the speaker that this must limit the distance at which the headlight can be of use, unless the headlight is to be placed very low on the locomotive. If I understand the suggestion correctly, if we are to limit the height of the beam at a given point below the signal, or below the engineer's eyes on the approaching locomotive, then we must limit the distance that that beam will be spread out longitudinally along the track or else we must lower the headlight to a point below its usual position.

At this point I might take up the question of the placing of the headlight on the locomotive. These locomotive headlights were all tested in the position in which they are used by the Big Four Railroad, namely, just in front of the stack on top of the boiler. Some of the roads use the headlight in front of the boiler, and on a level with the center of same. The interurban headlights tested were used in the position in which they are located on the interurban cars, about four or five feet above the track.

The only objection that I have heard to the mounting of the headlight below the top of the boiler front, is that sometimes it is of advantage for the dispatcher in the stations along the

line to detect the number of the locomotive, and this number is often placed in front of, or at the side of the headlight. The zone, and therefore the time, in which the dispatcher is permitted to note the number on high speed trains, is obviously greatly limited if that headlight is placed in front of the boiler. This position also, of course, involves limiting the distance of the illumination in front of the locomotive, unless the headlight is tilted upward.

With regard to the inquiry as to the ruling of the Commission, I will say that the Brotherhood of Locomotive Engineers first proposed the bill, including a minimum of 2,000 candle-power for headlights. Later these tests were made and a report was sent to the Commission. The conclusion of the report, in a nutshell was that the committee felt that a happy medium could be reached in a headlight more powerful than the present headlight, and of proper spectral qualities, which would enable objects to be detected at a greater distance than the present headlight, but not sufficiently powerful to interfere with signals. The Commission interpreted this statement as an argument in favor of reducing the candle-power of the headlight and changed the ruling from 2000 to 1500 candle-power, although I think that no one knows what the 1500 means, as it does not state whether it is with or without the reflector. Since the illumination does not follow the inverse square law the ruling should apply to the illumination in candle feet at specified distances in front of the headlight when equipped with a reflector.

The ruling of the Commission is that all of the roads in Indiana, beginning with one third of their equipment in July, 1910, one third in January, 1911 and one third in July, 1911 shall equip their locomotives with headlights having a minimum of 1500 candle-power.

In regard to the advantages of a more powerful headlight in detecting obstructions on the track, I will say that it is, of course, obvious that the more powerful the headlight, the greater the distance at which the objects can be distinguished but it was the feeling of the Committee that the detecting of obstructions on the track was a minor consideration when compared with the correct reading of signals.

With regard to slowing down to read signals, or after detecting objects on the track, I might illustrate my point by referring to the statement of one of the locomotive engineers when called upon by an officer of the road for certain information. The officer asked the engineer what he would do, when running seventy miles an hour, with a powerful headlight, if he saw an object on the track a quarter of a mile ahead, which would cause an accident if struck by the train. The engineer said that he would not apply the brakes to stop for it. The officer asked him for his reason. The engineer said that if he were to stop for every obstacle that he saw on the track a quarter of a mile away, that he thought might be struck by the locomotive, he would not be able to

make the schedule—that he depended upon the object getting off the track, and not upon stopping the train in advance of the object.

With regard to the use of signals other than lights, at night will say that the suggestion has been made that semaphores be used, and the lights on the headlight be dispersed rather than concentrated, so that the position of the semaphores would be seen at night sufficiently well to use them in place of the lights.

The distance of the headlight from the observer and the distance of objects along the track in the rays of the headlight are also important questions, and I am glad that they were brought up. It is surprising how inaccurate the judgment of an experienced railroad man is in determining the distance of an approaching locomotive, or even of objects on the track, as seen in the rays of a powerful headlight. This was tried out unofficially, and guesses anywhere from one hundred to two thousand feet, and sometimes up to a mile, were made of distances of objects in front of the engine, as well as distances in front of approaching locomotives.

Discussion on "Some Recent Developments in Exact Alternating Current Measurements". Jefferson, N. H., July 1, 1910. (See Proceedings for July, 1910.)

(Subject to final revision for the Transactions.)

V. Karapetoff: There are four classes of measuring instruments for measuring alternating current; the soft-iron type, of which the well-known Thomson inclined-coil ammeters represent possibly the best practice. Then the hot-wire instruments, the dynamometer type instruments, and the induction instruments, based on the principle of revolving field. All these classes of instruments are in common use, all possess certain advantages and disadvantages, but hardly any of them are adapted for precise measurements. Considerable effort has been devoted for a long time to adapt the d'Arsonval type of galvanometer, that is, an instrument consisting of a coil moving in the field of a permanent magnet, for alternating-current measurements. Dr. Sharp's instrument represents one of the possible methods of using direct-current galvanometer for alternating current measurements, namely, by rectifying the alternating current. However, there are other methods for obtaining the same end, and I wish to mention here those that I know, with a view of getting Dr. Sharp's criticisms in regard to these methods. Since he had to devise a new method, we are justified in assuming that the methods known heretofore did not possess sufficient accuracy, or for some reason were not convenient for his purpose.

The methods used so far for measuring alternating currents with direct-current precision instruments are based chiefly upon the thermal effect of alternating currents, either through a direct heating of wires, or by heating a thermo-couple. We have had before our Institute a paper by our friend Dr. Northrup on his "Comparator," an instrument devised for measuring alternating currents with great precision (Transactions, Vol. 24, page 741). The instrument consists of two parallel wires connected by a mirror. Alternating current is sent through one wire; the heat generated expands the wire and deflects the mirror. Then direct current is sent through the other wire, so that the other wire is also expanded until the mirror returns to its first position. The direct current is measured accurately with a precision instrument, for instance a potentiometer; The effective value of the alternating current is equal to that of the direct current.

Another instrument is Professor Duddell's "Thermo-galvanometer." There you have an ordinary suspension type coil, the ends of which are connected to a thermo-couple. The alternating current to be measured is sent through a stationary heater; the heater heats the thermo-couple, and the current generated turns the moving coil; so you can calibrate the instrument with direct current, and use it to measure alternating currents. One might naturally think that this type of gal-

vanometer is too delicate for ordinary measurements; but I lately saw it advertised in the form of a portable instrument for industrial work. Generally speaking, the disadvantage of this type of measuring instrument is that only a small and rather indefinite part of the heat generated in the alternating-current heater is transmitted to the thermo-couple.

This drawback has been recently eliminated in an instrument developed by Dr. Guggenheimer, in Germany. He ingeniously combines the alternating current and the direct current in the same circuit. The internal connections are similar to those of the Wheatstone bridge. Two opposite points of the bridge are connected to a non-inductive ammeter shunt, in the alternating current circuit. Two other points are connected to a direct-current milli-voltmeter. Four thermo-couples are connected in the four branches of the bridge in such a way that they are in opposition (by pairs) with respect to the alternating current circuit, and act in parallel with regard to the direct-current circuit. In this wise, alternating currents and direct currents both flow in the same circuit, and the full extent of the heat developed by alternating currents in thermo-couples contributes to the deflection of the direct-current instrument. The apparatus is made in a form similar to that of ordinary portable instruments. The Wheatstone bridge is in the base of the instrument, and the instrument, when used as an ammeter, can be provided with any number of external shunts, from one-half ampere to several thousand. The sensitiveness of the instrument is limited only by the sensitiveness of the direct-current milli-voltmeter used in it.

I should like to know what objections Dr. Sharp has to this or to any other devices used for precise alternating current measurement, and what advantage his synchronous rectifier has as compared to these?

L. T. Robinson: The necessity and the advantages of zero methods are brought out in the paper quite clearly. We all appreciate that these zero methods are always to be preferred if they do not introduce other complications that more than offset their advantages. The use of a direct current instrument as the detector is spoken of as distinguished from the use of the electro-dynamometer for the same purpose. In my experience, we have had no difficulty with the electro-dynamometer with separate excitation, and did get, as described, good results, and do now; therefore, we see no objections to it. There may be advantages in introducing the further complications, and these advantages may become more apparent as time goes on, but they are not yet fully apparent to me.

The difficulties with dynamometer instruments, due to suspensions springs, scales, etc., are also referred to, but for moderate currents, at least, we still find that this method is convenient, satisfactory and accurate, and while I still hope, as I expressed the hope a year ago, that some of the other methods would

ultimately win for the work in connection with the current transformer. We still find it more satisfactory to stick to the first method which was described a year ago and which we are still using.

In connection with electro dynamometers, there are certain difficulties which come up in the measurement of very large current; I think that if these difficulties which seem to be inherent in large alternating-current precision dynamometers can be removed and they are in a fair way to be removed, the ratio determination by dynamometers will still remain a formidable competitor of more complicated methods. As far as accuracy goes, there is, I think, nothing to be desired. If we can determine the ratio and phase angle of instrument transformers with a degree of precision which is well beyond the limits of accuracy which can be had with the instruments that they are to be used with, there certainly is no use in going further. It is an unnecessary refinement, and I do not think that any one would want to use these methods of measurement for truly precision work. When we come to such work we would need to use the dynamometer instruments or other instruments which Professor Karapetoff has referred to, directly on the work. Thus, there is hardly any use in carrying the refinement in instrument transformer testing beyond a certain point. I think Dr. Sharp's improvements in the contact making key are, of course, very important and satisfactory, and such a rectifier may ultimately be the right thing to use. As I had it at first, it would do the work, but as he has improved it, it certainly does a great deal better, and to show him that I mean what I say, I have copied his device as nearly as I can and incorporated it with mine, and have used it in that form for some time. I cannot testify any more strongly to the value of the device.

I think from the statements in the paper, it is apparent that some of the things I have spoken of as difficulties with these indirect methods have come up. It is only fair to say that we have been working for some time with the method which Dr. Sharp has described—have been doing this for more than a year—and I have come in contact with some of these same difficulties myself, and also some others that are not mentioned, but I think that ultimately the method will be worked out in satisfactory shape. The author of the paper refers to obtaining of average value of alternating currents by means of these reversing commutators. I think this will ultimately be something that will be of considerable value, and in that connection I would say that I have experimented somewhat with an instrument in which the reversing commutator and other means are made use of to determine directly the average current, the root mean square current is also used in the same instrument, so that the instrument determines directly the ratio between the two, and in that way the form factor, which is an important thing in connection with transformer losses and also

for several other purposes. In shifting the phase in the determination of the ratio of transformers, I think Dr. Sharp brings out quite clearly the points for which I have previously contended, that is, that it was hardly necessary in commercially good transformers to take this into account; when the phase angle is less than two degrees the correction term in the ratio formula may be neglected. Of course, it is true that we have had transformers where this phase angle is more than two degrees, but the demand for good transformers which is now well established, and which we cannot stop, and which should not be stopped, will certainly result in the production of transformers in which phase angles, like two degrees, will be unknown, and if such are offered for sale, I think they will be refused promptly.

The method of determining the distortion of wave form to which Dr. Sharp refers is most ingenious and satisfactory, and I think this will undoubtedly lead to some practical way of determining whether the wave form of a certain alternator comes within the requirements of the Institute standards or not —that is, to a short and direct way which will not involve the necessity of taking the wave with oscillograph or in some other way, to see if it comes within the requirements or not. It also seems to me that some way will be devised to handle the problem referred to, of obtaining Fig. 5 from Fig. 4, of the paper by direct measurement.

I would also emphasize the importance of being able to obtain tests of current transformers, by using a low value of impedance, in the secondary circuit. The method referred to of using mutual inductances is compared with similar methods using resistances, and then several advantages are given, but it seems to me that other methods have these same advantages, and others as well. I have not yet given up the idea that some method using thermo-couples will be the ultimate method, as no questions of wave form or phase displacement in determining the ratio can possibly modify the results. Thermal instruments have some peculiarities, and there are some difficulties in their employment, but at the same time, primarily, it is the correct principle, and I think that some means will be found ultimately so that they will be very generally employed.

In regard to the statement, " The magnetizing current is measured on open circuit the voltage being adjusted to the value corresponding to a given load of the transformer. It is best measured by supplying the current to the secondary or low current winding and computing the results in terms of the primary." This is undoubtedly true, but at the same time I am not prepared to accept this at present as the universal statement. It appears to me that this should be the correct way to do it, but at the same time, as I showed last year in my paper, in some transformers we have been able to do it and to get very exact results indeed, but I have since found that in certain other types we do not get this kind of results at all, and there is

something wrong with the way we do it, or else we do not understand the situation. I am not prepared to say what it is now—I desired simply to say that this statement, while it appears that it should be true, I do not think should be accepted, without more experimental proof, as absolutely covering all cases.

In regard to the statement, "It has been found possible to simplify these methods by the employment of one electro-dynamometer only, in phase angle test whereas previously two electro-dynamometers have been employed." In justice to what has been written on this subject, I revert to page 731, of the TRANSACTIONS of the Institute for 1906, where you will see the method using one dynamometer described in a discussion which I offered at that time on Mr. Curtiss's paper on Current Transformers. In fact, we have now been around the circle—I think I started with one, but finished with two, and Dr. Sharp started with two and finished with one. It is unimportant and it makes very little difference. The reason I prefer two instruments is that you can bring one instrument to zero, and have some one hold it there, and you can correct most variations in the circuit while the measurement on the second dynamometer is being made and thus determine the phase angle from one measurement. The way it is done in the paper is good, and in some cases perhaps is to be preferred. It seems to me, ordinarily viewed, it would be a little more direct to take one reading proportional to the sine of the phase angle then to take one proportional to the sine and another to the cosine, and from these readings determine the tangent.

In regard to loading transformers at various power factors, I am well satisfied with the arrangements which we have, but this, again, is a matter largely of what one can do handiest. We had plenty of reactances, and have simply taken meter parts and combined them with switches, etc.—there is little to say about the speed of using, and the convenience is about the same in either case.

The point referred to about determining the ratio of turns in current transformers, is good and could be given quite useful application. Of course, in my own work it is not often necessary to do this, as we have access to construction records, and it is only necessary to determine the ratio of turns in examining transformers of other makes.

The phase shifter illustrated in the paper I consider to be a very ingenious and satisfactory device, and I take this opportunity of complimenting the authors on the production of it.

With regard to the large current shunts, I do not approve of the construction as shown. It seems to me that they are of necessity somewhat inductive and I think a moment's consideration of the loops which are formed within these shunts, and the statement which Dr. Sharp made, that the phase angle is twenty minutes—would support this view. It is only necessary to squeeze the two sides of the circuit closer together to remove the

phase angle altogether, and with it the necessity of determining what the phase angle is, and the correction for it in the measurement. This would simplify the whole matter very greatly. I have recently devised a line of shunts with these features, but which I will not describe now.

The remainder of the paper is of interest to me, but I do not think you would be particularly interested in any remarks I could offer about it. In regard to the whole paper, I want to testify to my appreciation of what has been done, and to say that it pleases me very much to note that a subject which is of real importance, although it does not directly come into the field of all of us, still the results obtained are important to all, is being considered. I feel quite sure that if this development of methods and proof of results can be continued and we can be made acquainted with the work which is done, that we will all be benefited by it.

W. H. Pratt: Allusion has been made to recent work done in directly measuring large alternating currents and large quantities of alternating current power by direct methods as opposed to the zero methods. In the first place, I have always felt doubt about the zero methods of measurement, unless we have a very close approximation to the sine wave. The distortion in the current transformer may be taken care of all right, but it is necessary to have a close approximation to the sine wave to start with.

As to these direct measurements, we have recently found it necessary to make measurements of alternating-current power and to make them with a degree of accuracy that precludes the use of current transformers.

The great source of error in alternating current instruments of large current carrying capacity has been the eddy currents induced in the massive copper conductors. Previous attempts to minimize this trouble have consisted in using stranded cable, often flattened. This procedure helps a great deal but comes far from curing the trouble.

In the twisted cable, the individual conductors are not all similarly located, and, consequently, as the cable heats, the distribution of current flow is altered.

I believe that long ago the possibility of water-cooling instruments was mentioned, but I have never seen it applied until very recently, when we constructed a water cooled watt-dynamometer of the reflected type.

In the water-cooled instrument, the trouble from uncertain current distribution is entirely taken care of. The amount of current that can be carried in the water-cooled conductor is surprisingly great. The conductor that we employed in the dynamometer, I referred to, was a copper tube 5/32 in. internal diameter and only 7/32 in. external diameter, *i.e.*, the walls of the tube are only 1/32 in. thick. City water pressure is applied at one end so as to get a heavy flow of water through the tube. Under these conditions, this very small cross section of copper

will carry with about 6 deg. cent. rise a current of 1000 amperes. The flow of current could be easily doubled without causing excessive heating. At 1000 amperes, the current density in the copper is approximately 55,000 amperes per square inch.

It can be readily seen that by using a tube of the dimensions which I have just mentioned, that it is possible to make an instrument of very large current carrying capacity, having characteristics almost identical with instruments of 50 amperes capacity or thereabouts.

Of course in many places water-cooling cannot be applied, and to avoid the troubles that accompany the use of stranded cable, as ordinarily employed, we have used flat hand-braided conductors. Every individual strand is located similarly to every other strand and trouble from unequal conductivity, due to heating as well as eddy currents, are simultaneously avoided. It has been found possible to employ coils made in this way in portable instruments, obtaining thereby very high accuracy.

For some alternating current measurements, we have employed current shunts. Here again we have used direct measurements and have not stinted in the power consumed, often using, even for large currents, drops as high as 50 volts. By so doing, it is possible to proportion the apparatus so there is no question as to the relative distribution of the alternating current used in measuring and the direct current used in standardizing.

C. P. Steinmetz: There is one modification of the method of measuring alternating current which I do not see described,

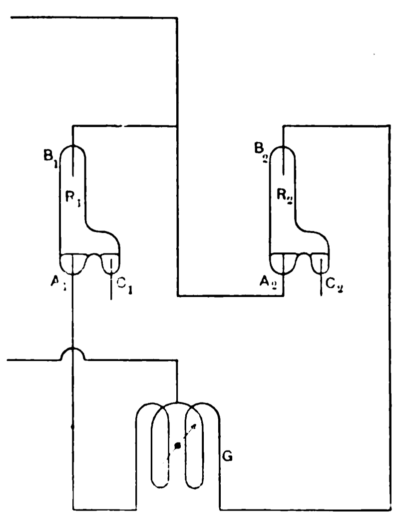

Fig. 1

and which appears to me to lend itself specifically to the measurement of the mean value of extremely small alternating currents of very high frequency—frequencies beyond those where me-

chanical rectification is possible. It is by the use of an arc rectifier, as diagrammatically sketched in Fig. 1. Let R_1 and R_2 be two rectifiers, with negative terminals A_1 and A_2, positive terminals B_1 and B_2, and auxiliary terminals C_1 and C_2, and assume, as not shown here, that between A_1, C_1, and between A_2, C_2, an auxiliary direct current arc is maintained to supply the conducting vapor stream for the main arc. The incoming alternating current connects to terminals B_1 and A_2, while the rectifier terminals A_1 and B_2 connect to the two terminals of the galvanometer G, and the center of the galvanometer coil connects to the outgoing current, as shown in Fig. 1. In this case the galvanometer measures as direct current the mean value of the alternating current. The arrangement, which can be modified in various ways, is, as you see, that these two rectifiers completely rectify the successive half waves of the alternating current, irrespective of how small they are, and how high their frequency is.

Clayton H. Sharp: Mr. Karapetoff wanted to know what the criticism was of the old method and of the apparatus which is at present available. I would say to him there is not any criticism made. The purpose of the paper was not to criticise old methods, but to present something that is a modification of these older methods, or has some elements of novelty in it. I would, however, call his attention to the fact that this paper deals chiefly with zero methods, and that the instruments of which he spoke are deflection instruments, also that, being thermal instruments, they would not be well adapted to zero measurement work.

Mr. Robinson spoke of the complication of the method here presented as compared with electro-dynamometers. When electro-dynamometers are available and the work is done in the laboratory, rather than under service conditions, there is no complication in their use except that involved in any non-zero method. I maintain however that there is no complication in the method which has here been presented, and if one has not a row of electro-dynamometers, it hardly admits of question that the rectifier and direct-current galvanometer and shunts represent even less complication than is involved in the construction of the whole line of electro-dynamometers, especially as they are subject, particularly in the higher values, to difficulties of their own. Moreover shunts can be constructed for much larger currents than electro-dynamometers can be constructed for.

I want to take issue with Mr. Robinson in another matter, and that is his statement that it is unnecessary to go into the measurement of these transformers to any higher degree of refinement than the instrument which is to be used in the secondary side is capable of. I do not think he is right in that statement. I think we want to do something better than direct reading instruments will do. If our transformer is capable of better work through its constants being determined to a higher

degree of accuracy, we ought to do it, and then to bring up the instrument on the secondary side to a higher standard of accuracy to correspond thereto.

As to Mr. Robinson's contention that the phase angle is a negligible quantity in determining the ratio, undoubtedly the ratio can be determined, even though the phase angle is neglected. However, the phase angle needs to be known for accurate reading with watt hour meters and wattmeters, and the method presented here includes determination of that angle without introducing any complication into the work.

L. T. Robinson: I fear Dr. Sharp misunderstood me. I appreciate the importance of the measurement of the phase angle, and brought that out in a previous paper. It was the importance of the lag—the necessity of taking into account the phase—in determining the ratio, and I would also say I fully appreciate, and described the advantages of most of the zero methods in the paper which I presented a year ago. That is not the point—it is simply the particular method of carrying out these zero methods that seems to me a little more complicated than is necessary.

Clayton H. Sharp: Regarding Mr. Robinson's reference to the paper of a year ago, I want to say that this work has been in active progress in our laboratories for well on to three years, and the method described is not a new thing with us. I described it briefly at our last convention.

William W. Crawford: I have very few points to add to what Dr. Sharp has said. In answer to Professor Karapetoff's inquiry as to the particular advantages of the rectifier, as used with the direct-current galvanometer, I would like to say that by rectifying the alternating current, the entire energy available in the galvanometer circuit can be applied to the galvanometer. A device which converts the available energy into heat, and then, by means of a thermal or some similar effect, regenerates a very small proportion of this energy into current, cannot have as great sensitiveness.

In the measurement, by deflections, of moderately large quantities, the use of a direct current instrument with a synchronous reversing key is not as accurate as the ordinary alternating current instruments.

Mr. Robinson has referred to the difficulties encountered in this method. In the article we have described in full the difficulties we have encountered in this method, such as leakage between the motor circuit and the galvanometer circuit, and imperfections in the mechanical actions of the rectifier. It has been my experience, however, that with equal sensitiveness in the electro-dynamometer and the direct-current galvanometer, the leakage effects would be nearly equal. Of course, that may be contrary to the experience of others.

Mr. Robinson has suggested an alteration in the design of the heavy capacity shunt—that designed for 5,000 amperes.

The calculated phase displacement at 60 cycles of this shunt, based on the distance between the outgoing and returning leaves of the plate, amounts to about eight minutes, whereas the measured value is twenty-two minutes. That eight minutes is the amount we could probably get rid of by squeezing the plates together. There is an amount of fourteen minutes there which is introduced by the terminal blocks, which form a considerable loop in such a manner as to affect the plates unequally. It therefore is necessary to measure the phase angle of the shunt, and I think this is a desirable precaution, even though all indications of design would point to the shunt having a zero phase displacement.

DISCUSSION ON "DETERMINATION OF TRANSFORMER REGULATION UNDER LOAD CONDITIONS AND SOME RESULTING INVESTIGATIONS". JEFFERSON, N. H., JUNE 29, 1910. (SEE PROCEEDINGS FOR JULY, 1910.)

(Subject to final revision for the Transactions.)

Charles Fortescue: The method of measuring the regulation of a transformer, given in this paper, appears to the writer to be open to serious objection for the following reasons.

1. Assuming that adjustment for e_{min} has been satisfactorily effected, the reading across $f\,g$ will not be the regulation of the transformer. It is true that in the example cited by the author of the paper the difference between the value read and the true regulation of the transformer, provided all other conditions of the test are satisfactory, would be negligible. But for a transformer having high reactance volts, in comparison with the ohmic drop, this method of measurement would introduce an appreciable error.

2. If the value of e_{min} is large compared with the regulation of the transformer, a very small error in the observation of e_{min} will produce a large error in the adjustment of electromotive force $f\,g$. In the examples cited in this paper it happens that the value of e_{min} is comparatively small, and therefore the error in adjustment of $f\,g$ is negligible.

3. The accuracy of the method is also dependent upon the resistance of the galvanometer used for adjusting $f\,g$ by means of e_{min}.

With reference to the proposed method of obtaining data for calculating the regulation, it is evident that the accuracy of the results obtained depends upon the resistance of the voltmeter used, of the shunt of the wattmeter and the size of the transformers on which the measurements are made. If the two transformers, A and B, are exactly alike, and we denote the true impedance by Z, and assuming that the reading of the voltmeter is V, I being the load current and R the resistance of the voltmeter, we have for the correct value of Z,

$$Z = \frac{V}{I - \frac{2\,V}{R}}$$

all the quantities being combined in their proper phase relations. It is apparent from the above that the value read on the voltmeter is too small for the true impedance volts and the phase difference as obtained by the voltmeter and wattmeter together is too small. If the shunt of the wattmeter has a different resistance from voltmeter, another source of error is added. For small transformers and with the usual commercial low reading voltmeters, the error due to the above conditions may be quite marked.

The curves shown in Figs. 5 and 6 show remarkable agree-

ment between the regulation measured and calculated by the two methods proposed. But it is possible that the errors due to the instruments in both cases are approximately the same.

In Table 2 it is seen that the impedance volts steadily rises in value for a given current as the impressed voltage is reduced. The author argues from these results that the reduction of the flux density may cause increase in the leakage flux due to the higher permeability of the magnetic circuit. In the opinion of the writer, this is very improbable since in the first place the permeability of the iron at the low induction of the short circuit test is in commercial transformers about the same as that at the working induction. In the second place, with primary and secondary windings interlaced, as they are in such transformers, the length of the leakage path in the iron is very small compared with that in the air, and the density of the leakage flux is lower in the iron than in the air, the effect of the reluctance of the iron on the reactance e.m.f. of the transformer is, therefore, inappreciable. It is possible that the difference in impedance with varying induction in the test referred to, may be attributable to a change in the wave form of the primary impressed e.m.f. due to the method of changing its value.

In order to be able to form some estimate of the errors in the method, due to the causes outlined above, it is necessary to have data on the instruments used, and some knowledge of the wave form of the impressed e.m.f. under the various conditions of the test. It would be extremely interesting to obtain a comparison between the short circuit method and that proposed, with all errors in measurements, etc., eliminated.

To conclude, the writer is of the opinion that the results given in this paper are not sufficient as a basis from which to judge the merits of the two methods, of obtaining data for calculating regulation, that is to say, the old method and that proposed by the author. The latter method has had some commercial applications, but for the reasons given in the preceding discussion by the writer has not been widely used.

Results of some tests made on a standard lighting transformer 2200/220 volts 60 cycles

USING METHOD II

Primary volts	Sec. amp.	Volts imp.	Watts
2000	20.2	5.38	76.8
1000	"	5.3	76.8
520	"	5.32	76.8
73	"	5.3	76.8

Corrected average volts impedance = 5.36.
Corrected watts 77.

Using short circuit method

Impedance volts	5.42
Watts	79.70
Amperes	20.2
Corrected watts =	79.4
Volts impedance =	5.42

The difference between the two methods is

Watts	3.2 per cent
Volts	0.8 per cent

This commercially would be considered a good check.

E. A. Wagner: In regard to this paper of Mr. Shane's my views agree with Mr. Fortescue's. I think a small error in measuring the voltage e' by the galvanometer is apt to bring in a large error in the determination of the regulation. The galvanometer undoubtedly will have a certain amount of lag, which will cause an error in the angle, and this error will account for the discrepancy shown on page 1100 in the two impedance triangles. Furthermore, I do not think that the use of three transformers will be a good commercial proposition, as this method of measuring the regulation is intended to be. There is no question but what a simple and accurate means of measuring the regulation directly is very much desired by those having a great deal of transformer work, but I think the method of calculating the regulation through determining the resistance and phase angle of the transformers will give sufficiently accurate measurements and determination of the regulation for commercial purposes.

L. T. Robinson: In reference to Professor Shane's paper it is undoubtedly true that in some transformers at least the regulation may not be accurately found by the usual method of determining the impedance triangle from the volts required to force full load current through one of the windings with the other short circuited.

The required impedance volts may be determined by means of reading the volts and amperes and computing the $I\,R$ component from the measured resistance of the transformer or the watts can be measured and the energy so read considered to be the $I^2\,R$ loss. Sometimes these two methods agree closely and with the measured regulation but sometimes they do not. Also it is necessary to know the regulation and ratio of some transformers especially instrument transformers with very great precision. In fact it may be accepted as a general statement that it is not safe to determine ratio and regulation of transformers by any method of calculation until the method has by accurate measurements been proved correct and reliable for the actual type of transformer to be dealt with.

Although the value of determining the impedance triangle under load conditions, as shown in the paper in Fig. 4, as against determining it by similar means at low density with a short circuited winding seems quite apparent, still the chief reason for

believing in it is the excellent agreement between regulation calculated using the values of the impedance triangle determined in this way, and the tested results rather than any theoretical considerations that might be urged in advocating the method used. There are so many secondary actions within transformers that may or may not affect the ratio and regulation that a ready means of determining their effects directly is always of interest and value.

The test that is described is one that requires two or really three transformers. Two of these are exactly alike and the third is a small auxiliary transformer *C*. The voltage of the loaded transformer *A* is connected to one terminal of the small transformer *C* which is connected to have its voltage in the same direction as *A* and opposed to *B*. This small transformer slides, etc., then forms a ready means of getting voltage in phase with *B* varying by small steps.

The point *f* Fig. 3 on *C* corresponding to e_{min} is found and the regulation volts are read from the auxiliary transformer *C*.

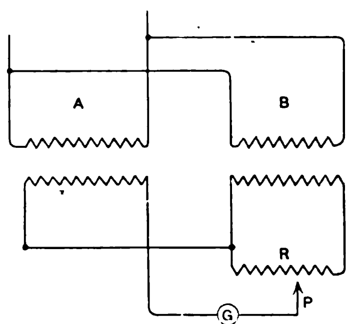

FIG. a

It is not always easy to get two transformers exactly alike. Perhaps some of the most desirable cases where it would be necessary to have an accurate measure of the regulation would be large transformers, where it may be that only one at a time is made. It is, therefore, proper to consider some means whereby the methods of the paper, which are in a sense quite similar, although differently carried out, to methods which have been developed for potential (instrument) transformers may be used to get the same results as those obtained in the paper, without the necessity of employing the two identical transformers.

For the second or unloaded transformer *B* there may be employed any transformer of known characteristics with a resistance across its secondary, and the secondary volts delivered by it changed by a slide resistance *R* Fig. *a*, or the test could be made at low voltage (2200 and under) using resistance on the primary side and omitting the auxiliary transformer altogether, Fig. *b*.

For ratio and regulation testing it is not necessary to have the transformer B unloaded (as shown in Fig. 1, Shane) because the phase displacement between primary and secondary current due to carrying moderate load would be small and almost always in a direction to bring the voltage on the secondary of A and B more nearly in phase so that E_{min} may be read as a smaller value. The regulation will be found from the change in position of the contact p between the points where the E_{min} balance for no load and full load on the small transformer C is found, the volts per step on C being known from a voltmeter in the secondary of B or A. If the connection of Fig. *a* or *b* is used the absolute ratio also may be read by knowing the resistance R and the ratio of transformer B accurately. If a standard instrument transformer is used for B loading can be so arranged as to get practically zero phase between A and B at no load on A. This is evident from the diagram, Fig. 9, where the impedance volts is in line with the volts e''. The closing voltage E will also be along the same line and be in phase with e''. This is the condition where the power

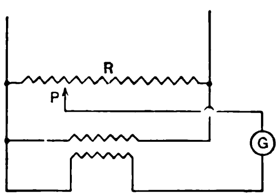

FIG. b.—Arrangement for low voltage, 2,200 and below

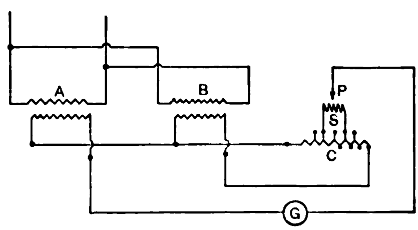

FIG. c.—Arrangement for voltages of 110 to 60,000 or more

factor of the secondary load is the same as that of the impedance triangle of the transformer. Such a condition may be secured in practice by having the load on the transformer B reactive or by connecting reactive coils on to load transformer B in parallel with its non-inductive load.

For low voltages the resistance R may be of any desired amount (about 5 or 10 ohms per volt) and may be used with any suitable detector, (G).

For use on 110 to 220- or 550-volt secondaries it would be possible to provide a small auxiliary auto-transformer of known constants with or without the slides, that Professor Shane has shown, refer to Fig. *c*. It would then be easy to get regulation on any transformer of 110, 220 or 550 volts secondary if another transformer to be used as B having anywhere near a similar ratio was available without the necessity of getting two transformers alike. For regulation test the constants of transformer B need not be accurately known and both ratio and regulation may be obtained if the constants of transformer B are known but still A and B need not be alike. Also with the constants

of B accurately known proper loading of its secondary can produce zero phase angle. (Zero phase angle is not always present in transformers at no load.) In either case the low reading voltmeter for reading regulation is not required.

If zero phase angle is produced on B then the reading of E_{min} where A is loaded is also a measure of the phase angle for

$$\text{Sin} \left\{ \begin{array}{l} \gamma \text{ in potential transformer} \\ \beta \text{ in current transformer} \end{array} \right\} = \frac{E_{min}}{e''}$$

Quite good accuracy, on account of the very small angle usually found, may be obtained in this way with any suitable means of determining the point f and of reading E_{min}. Professor Shane has found that commercial alternating-current voltmeters may be used; also he has employed a special indicator for the purpose. An indicator similar to that described might be used to measure E_{min} as well as to determine the point of, but perhaps some form of dynamometer, separately excited, if need be, and with or without iron might be used, or any thermo galvanometer scheme, or commutator device, in fact any of the special devices referred to at the Convention last year* and this year† in connection with ratio and phase angle testing of instrument transformers.

To me the greatest value of Professor Shane's paper is in showing that the somewhat refined methods by which exact regulation, ratio, etc., may be determined for instrument transformers are useful for, and may be easily applied, to the more general problem of the commercial testing, of lighting and power transformers.

Ralph W. Atkinson: Professor Shane has thrown much light on some complexities of transformer theory. Much of the transformer theory is such that to the ordinary engineer, practical proof is necessary for entire confidence in the results.

It is well known that the effective resistance of a transformer as measured by the wattmeter on short circuit is greater than the effective resistance obtained by measurements with direct current. To determine the correct impedance triangle, the resistance as determined by the wattmeter must be used. Otherwise it is quite possible to make a large error in the determination of the reactance. If there is a difference in the case in point, it would tend to bring the results obtained by ordinary methods nearer to those of Professor Shane. If the results given in Table 2 line 9 be taken as correct for short circuit conditions we may obtain a value of regulation only about $\frac{2}{3}$ as far from curve A Fig. 6 as is curve B.

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* L. T. Robinson, Electrical Measurements on Circuits Requiring Current and Potential Transformers, A.I.E.E., TRANSACTIONS, 1909.

†Sharp & Crawford, Recent Progress in Alternating-current Measurements A.I.E.E., 1910.

The additional loss as measured by the wattmeter may be of very considerable importance, though generally small in small transformers. It may be calculated by a not very complicated formula while the general explanation of the cause is very simple. The loss may be regarded as due to circulating or eddy currents induced by the field in the coil space due to the load current of the transformer. The field due to the magnetising current is very small and hence causes no loss in the copper. Therefore this copper loss is the same at full voltage as at no voltage. However, Professor Shane's tests show the total copper loss to be greater at the full voltage of the transformer. It would be interesting to know the cause. A possible explanation is the copper loss in the primary due to the exciting current. However the 4 per cent difference in copper loss at full voltage and no voltage can not be accounted for by less than about 4 per cent core loss; moreover this does not account for the reactance on full voltage.

Another point; with transformers connected for a heat run by the ordinary loading-back method, the copper losses are the same as under the short circuit conditions and hence there might be considerable error in the temperature rise obtained on transformers where the "load losses" are large.

It is probable that tests on a transformer having greater proportionate "load losess" would settle definitely their nature. The writer hopes the discussion will bring out the cause of these "load losses"

Adolph Shane: With reference to the errors liable to result in the use of Method I for transformers having large reactance values, as referred to by Mr. Fortescue, I may say that this matter has been given some consideration. The leakage reactance at the worst is always small as compared to the value of normal voltage. Therefore, though I frankly admit that the method is theoretically an approximate one, it affords in nearly every case a truely negligible error. The assumption made is, that the base of a narrow wedge-shaped triangle is equal to the hypotenuse. As long as the angle between these two sides is very small this approximation is legitimate. It would take a leakage reactance of considerable value (third side of triangle) to cause an error of practical importance in the above assumption. By examining the vector diagram of the transformer it will be noticed that this error is a maximum at unity power factor and begins to disappear as the power factor lowers. At one point on the regulation curve the error is theoretically absent, namely when e_{imp} is the value of the regulation. But, excepting near-unity power factor, this error can never be suspected of being important, because the $I\ R$ value is the only other quantity to ever tend to widen out (at very low power factors) the small angle referred to above, and this value is always small as compared to normal voltage.

Therefore, let us consider the worst possible condition, namely

at unity power factor, and further let us choose three times the reactance value as observed in the tests. We will consider 12.75 volts as $X\ I$ instead of 4.25, the other values remaining as before. Under these circumstances the regulation volts is really 7.47. By solving the wedge-shaped triangle $e_{r\cdot g}$ is found to be 7.82. The error is thus about 4.7 per cent. This is caused by a phase angle of a little more than 3 degrees between the line and secondary voltages. This displacement is usually considerably less in fairly small capacity transformers.

A word about the galvanometer used in these tests. It was a small piece of iron suspended on a thread. A coil surrounded the iron. Such a detector may be made as sensitive as one pleases and is not intended to indicate quantitative results, but a definite minimum point only. Criticism was made of the lack of sensitive adjustment in the method. Figs. 5 and 6 of the paper seem to show a sufficient degree of accuracy and necessarily assume some precision of adjustment. Indeed, where e_{min} had some value, as at unity power factor, a low reading voltmeter was used at times to secure adjustment more quickly and with good results. Of course, the detector must be well damped. Great accuracy of adjustment is only imperative when e_{min} has some considerable value. Fortunately an alternating current instrument (indicator) is sensitive upon the scale. It is not so sensitive near zero, but neither is extreme accuracy of adjustment necessary when e_{min} is quite small. The accuracy of adjustment may always be checked by the equation $e_{imp} = \sqrt{e_{reg}^2 + e_{min}^2}$. Such checks are often desirable and insure correct results.

The error due to current consumption of instruments is negligible and is of no greater magnitude than might be caused by a voltmeter connection for any test.

As to the use of three transformers in Method I, some may consider such an undesirable complication. If so, I would suggest to them Method II, the calculated method. The work at the desk is the same as in the method now popularly used; only the method of obtaining the data is modified.

As for the present methods of obtaining transformer regulation being sufficiently accurate, it would seem from curves 5 and 6, that the primitive method of reading no-load and full-load voltages, and obtaining the difference may give more accurate results. If we desire the truth, then we should find some scheme for ascertaining the *accurate* value of transformer regulation. Of course, I do not think for a moment that the methods presented here are the only ones feasible for arriving at more accurate results. I merely submitted these two proposed methods for discussion, so as to pave the way toward truth.

Discussion on "The Design of the Electric Locomotive". Jefferson, N. H., July 1, 1910. (See Proceedings for July, 1910.)

(*Subject to final revision for the Transactions.*)

Wm. McClellan: I should like to emphasize the absolute necessity of designing electric locomotives with reference to track conditions.

As speeds increase and loads get heavier, maintenance of track is difficult in any case. It is especially so, however, when trains of a great variety of speeds pass over the same track. Roadway men know how difficult it is to fix proper elevation of rail, surface and align the rail, and bed the ties so that the result will be equally good for low-speed freight trains and for high-speed passenger trains.

In regard to the question of interchangeability, there is another feature which is of great importance. In freight service, we cannot dispatch trains and adhere closely to the schedule with the same degree of accuracy that we can in passenger service. We can design a locomotive for handling a certain kind of passenger service and it is quite likely that the locomotive will not often be used under very different conditions. On the other hand we may design a locomotive for a certain kind of freight service, and instead, for example, of going over the road with few stops at a good speed, traffic conditions may compel it to start and stop with great frequency, or run at an extremely low speed for the bulk of the time. To put it differently, the freight locomotive may be designed for through service, but may be compelled through the exigencies of conditions to do the equivalent of switching service. This does not apply to the electrification done so far which has been chiefly on tunnels and grades.

A. F. Batchelder: There are a few points to which I would call special attention and about which I cannot fully agree with the paper.

As to the order of importance of the different points of design, I cannot agree that the dead weight per axle is necessarily second. A great many differently designed locomotives have been built and operated. So far as my experience goes, I have not seen as yet, neither have I been able to find anybody that has seen, any design where the dead weight has had any detrimental effect on the track as long as it is limited to the weight of the motors, the journal boxes, spring saddles, and with the rotating parts balanced and the trucks properly equalized.

There are electric locomotives in regular operation that have dead weight per axle as high as 17,000 lb., and so far as I can learn, there is no indication that this dead weight has any bad effect on the road bed or track.

Of course it is well understood that on steam locomotives where the wheels are not well balanced and the locomotive running at high speeds, the unbalanced weight has a bad effect on the rails and road bed.

Relative to the height of the center of gravity being important, I believe a high center of gravity will assist in making an easy guiding locomotive, providing the spring supported portion is carried on journals placed between the wheels, making the spring centers approximately 42 in. apart, as is the general practice on steam locomotives; but with electric locomotives with outside journal boxes where the spring centers are placed approximately 80 in. apart, a high center of gravity say from 60 to 75 in. is but very little assistance to making the locomotive guide easily.

The feature desirable to obtain is the rolling effect in entering curves, and it will be seen that the rolling effect will be much less with a high center of gravity locomotive where the spring centers are 80 in. apart than it would be if the spring centers were only 42 in. apart. It will be seen that in order to obtain the same effect where the spring centers are 80 in. apart it is necessary to have the height of center of gravity above the point of thrust nearly twice as great as with spring centers 42 in. apart.

The paper also speaks of the different opinions of engineers and their choice as to the weight per axle. It has been my experience that it is not the opinion of the engineers, but the physical conditions such as the weight of rail, and strength of bridges and road bed, that determine the weight per axle allowed, and the railway engineer is in position to know these, and insist upon designing the locomotives to suit the conditions.

Another point that the paper brings out very nicely is the necessity of concentrating the mass of the locomotive as near the center as possible. I might add that it is also desirable to make the guiding wheels as far forward of this weight as possible, as it is well understood that if we have something to guide, the longer the handle the easier it is to manage.

I might also mention that it is the spring-borne portion of the locomotive that is the most difficult to manage. It is this portion that can set up oscillations and build up a movement that is difficult to stop without doing damage to the track by the guiding wheels. If the greater portion of the weight of the spring-borne part is concentrated near the center or well back from the guiding wheels and with a damper to prevent its building up oscillation, it is perfectly practicable to guide a very heavy locomotive without damage to the track.

Every locomotive truck that runs on rails is bound to oscillate from one side to the other, on some portion of the railroad, and it is practically impossible to make a locomotive run without doing this. Therefore, it is necessary for us to accept this oscillation as being inherent, and for high-speed locomotives, we must design so that this oscillation will do no damage.

It may be interesting to examine the design of the locomotive shown in the accompanying illustration which I believe embodies most of the desirable features discussed and which we

have worked out to meet the requirements of heavy trunk line service; it has a tractive effort of nearly 30,000 lb., continuously, and a maximum tractive effort for short intervals of time of 80,000 lb.

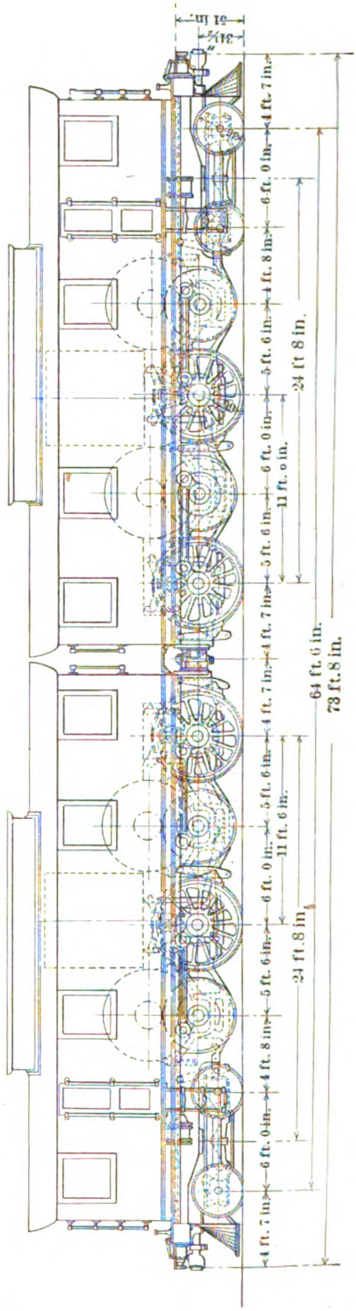
It will be noted that it has a reasonably high center of gravity, narrow distances between springs, the weight of the spring-borne portion well back from the guiding wheels, motor flexibly supported, and each driving axle is driven through quartering cranks and side rods from a jack shaft which is driven by the motor through spur gearing.

We have looked into this design very carefully and find it possible to build it with motors of sufficient capacity for the heavy trunk line service on mountain divisions and keep the total weight within reasonable limits.

In general the locomotive is made up of two American type engines coupled back to back having two driving axles and a two axle leading truck on each section.

It has been well proven that the American type engines operate very satisfactorily at all speeds on our American railroads and for this reason, I believe that this type of electric locomotive will operate the same under the same conditions.

Frank J. Sprague: I cannot express my belief as to the best type of electric locomotives, for I am a member of the Electrical Commission of a prominent railroad company which will soon be engaged in the task of dissecting proposals which have been accumulating for the past eight or nine months, from manufac-



turing companies, involving quite a variety of locomotive designs as well as methods of motor operation. It would, therefore, be improper for me at the present to express any preference for a particular design, even if I had any. As a matter of fact, I am of an open mind.

We can all agree with the authors in the general statement of the requirements of an electric locomotive, which might more tersely be stated to the effect that we want to get all that we can in capacity and good tracking characteristics for the least money. That I think is the argument which will appeal in behalf of electric traction to railroad officers and engineers. Not only must we seek all that is possible in the matter of capacity and good riding qualities, but also incorporate in the locomotive all that is practicable which has been found to be good in the steam locomotive, but which is not necessarily individual to, or especially characteristic of steam operation, and also all that is good so far as possible in electric operation. Now, how? I suppose there are few engineers of maintenance who do not at times think the superintendent of motive power ought to scrap most of his engines, and likewise it is a good natured and patient superintendent of motive power who does not occasionally condemn the track engineer for the condition of his track. Perhaps that is stating the facts a bit strongly, but it illustrates the feeling which exists oftentimes between two great operating departments of our railroads which should coöperate, because after all the locomotive and the track are married, and you cannot divorce them. Each affects the other, and neither has the right of way over the other; both are vital to the operation of the railroad.

The authors describe various methods of motor mounting and their effect upon the construction of the locomotives. I find it more convenient to consider locomotives, at first, irrespective of their motor mountings, and as divided broadly into three classes: locomotives with fixed wheel bases, either with or without a leading truck, the truck having either one or two axles; locomotives with bogie trucks, symmetrical or otherwise, and either linked together or independent; and articulated locomotives, that is, made up of two sections each having drivers forming a fixed wheel base, and with a bogie truck, the two parts being hitched back to back. There are many modifications of these types. Each of these forms can have a variety of motor mountings. A typical example of the first are the locomotives of the New York Central & Hudson River Railroad; of the second, the locomotives running on the New York, New Haven & Hartford Railroad, on the Great Northern, and in the Detroit Tunnel; and of the third, the locomotives which are being installed on the Pennsylvania railroad. Motors can be geared, according to my original practice, and there are some scores of thousands running that way, many of them at almost the maximum speeds that are attained by any steam locomotive

in this country; that is, there are plenty of interurban roads on which bogie truck cars, with motors geared to the axles, are running up to sixty miles an hour without materially bad effects on the track. That method of construction has certain advantages which have been well expressed by the authors. Then there is the gearless type of motor, one which has appealed in many respects to every engineer who looks alone to the question of the simplicity of electric operation, because of the removal of every detail of side rod, extra bearings and gears as a necessary connection between the motor and the wheels. The gearless locomotive has some very distinct advantages, but also some distinct disadvantages. Space limitations, necessarily are somewhat exact, and part of the dead weight is carried on the axles; it may, however, be almost entirely spring-borne. The wheels are of moderate diameter, and the capacity of the machines, if built for low speeds, somewhat limited.

Then there is the side rod locomotive, which now seems to be coming into vogue, having been appropriated from steam railroad practice. There is also the combination of the geared and side rod locomotive, as illustrated in the drawing shown by Mr. Batchelder. One thing we must bear in mind, and that is the further we get away from direct gearing, or from gearless motors, the further we get away from simplicity. Every locomotive design must be a compromise; it cannot be one which is limited primarily by the kind of current one is going to use, nor on the other hand by the desire for simplicity; it certainly must not be limited by the demands of the steam engineer.

The latter has handed to us a morsel which we are rolling under our tongues with a good deal of avidity, and which is expressed several times in the paper presented this morning by the phrase "high center of gravity." I agree with Mr. Batchelder that the question of high center of gravity is less important than many other things in the construction of an electric locomotive, and I consider it perfectly possible to build a locomotive with a large disregard to the center of gravity, which will operate satisfactorily at either low or high speed. What is vital is that every wheel on a locomotive shall be independently shackled, if I may use that expression, so that it can have reasonable vertical and lateral movements to meet track irregularities without disturbing any more than necessary the balance of the locomotive, or the position of the superstructure. Of course, if wheels are rigidly mounted in bearings so that they cannot traverse in any direction without moving the whole mass of the locomotive we have a condition which is intolerable, no matter whether it is in a steam or an electric locomotive.

I will refer to the developments on one or two locomotives which will illustrate some practical points. Let us first consider the conditions which take place when a locomotive is running, both at slow and high speed. Every road is made up of tangents and curves. If we had a dead true surface and alignment,

continuous rails and close gauge, it would not make much difference on a tangent whether high or low center of gravity was used, or what the springs were. With like conditions on a true curve, it would, after entering the curve, make little difference where the position of center of gravity is, because, after all, the flange of the wheel and the head of the rail are in intimate contact, and must remain so. Of course, we do not have these conditions, and therein lies the necessary for building locomotives to meet the actual conditions. However, with all the variations of surface and alignment, the track does not come up and hit the locomotive in the face, or give it a slap on one side. We have a pair of wheels slightly coned, and a certain lateral movement, traveling on two uneven rails, and as Mr. Batchelder has explained, it is impossible for two cones to so travel and maintain a central position, even on a true track. There is a tendency for these wheels to travel first one way and then another. The more slowly the locomotive moves the more difficult it is to traverse the rail, the faster it moves the more easily will the wheel traverse to one side or the other, the more severe will be the blow of the wheel when it does so traverse, and the heavier the blow which the flange will give to the rail when it recoils. You are all familiar with the early practice in regard to dynamos, putting a spring on the end of the armature to make the armature traverse back and forth to bring about an even wear of the commutator and brushes. The faster the armature traveled the easier it was to get it to move laterally. If you gave it too much play, a sharp push would drive it with a violent hammer blow against one bearing, and it would then rebound and strike the other. That happens on the locomotives at high speed on the rails as well as on the fast turning armature of a dynamo.

It has been said that with a high center of gravity, when you strike a curve the mass of the locomotive rolls over, the center of gravity goes towards the outer wheels, and the pressure on the outer rails is increased, thus increasing the rail resistance. I wonder if anyone who has made this statement has really investigated the problem to find out how far the center of gravity does travel, and what is the actual increase of pressure on the outer rail. If the rail is not properly banked and properly spiked to the ties, it would be better not to attempt to run a high speed locomotive on curves, because the increase of side pressure on the rail would be such that the ties would never hold it in place no matter what the increase of top pressure. The essential thing which takes place is the introduction of a time element before the flange has to take the entire pressure, as, of course, it eventually must.

On the New York Central, and also on the New York, New Haven & Hartford locomotives, certain characteristics early developed in practice which made it advisable to make some changes. The original Central locomotive had a fixed wheel base with four driving axles, and a pony truck at each end.

This truck may be described as a triangle, pivoted at the apex, and driving a single pair of wheels at its base. It was spring centered to normally maintain a central position. On the trial runs, at high speed on a tangent, some oscillation developed, with resultant side pressure on the rails. This was corrected by damping the motion of the truck, in other words, steadying it.

Shortly after the equipment was put into regular operation, there was a grave accident to a double header light train running at high speed, which some people have taken as a basis for a criticism of that type of locomotive, and various comments about the position of the center of gravity have appeared. A writer in an engineering magazine some time ago referred to this accident in a critical sort of way, not by name but by plain inference, and said that the responsibility for the accident was probably due to the low center of gravity. As voicing the admitted findings of every investigation committee, that statement is unwarranted. Referring to this accident, it is a curious fact that the locomotives never got away from the track; some of the wheels jumped the rails, but the coupled locomotives did not topple over, nor get away, notwithstanding their mass and the high speed at which they were traveling.

The same machines, without any change, were in operation for a long time subsequently, and are in operation to-day. Sometime since, however, a change was made which for some reasons I think was advisable. This did away with the single wheel truck, and substituted therefore a four-wheeled pivoted truck, an experience through which the steam locomotive has also gone.

On a curve such a truck yields easily, as it first turns on a pivot, instead of attempting to at once turn the mass of the locomotive. Then the forward wheel acting as a guide, with the rear as a fulcrum, helps the head of the locomotive around; in other words, the truck is the handle for turning. That is one improvement, but another was also introduced, and it was so good that our steam friends applied it to certain types of their steam locomotives; this was to give a greater lateral, but spring-resisted traverse to the wheels. I make it a practice, in going to and from my summer home, to ride on these locomotives to watch their operation. They run on old and new track, up to a speed of sixty miles an hour, and I find them very satisfactory.

It is a curious coincidence that on the New Haven road a train came within the closest shave of a disaster of even greater seriousness, when, running at high speed, two of the locomotives left the rails at the bridge at Greenwich, with the result, most fortunately, that but one person was killed. The wreck, however, was a pretty bad one. An immediate inspection of the track, following back a considerable distance, is reported to have disclosed some lateral displacement of rails. These locomotives, it will be remembered, have bogie trucks, spring sus-

pended motors, and a somewhat higher center of gravity than the Central's. The difficulty developed has been largely corrected by extending the wheel base, and putting a pair of leading wheels on each truck. I think in this respect they are now running satisfactorily.

It has been stated that a non-symmetrical locomotive is essential to prevent oscillation in a horizontal plane on the track. I think the term is more or less misunderstood, but if we take the locomotive on a whole, I cannot agree with that conclusion. I believe that a symmetrical locomotive, whether it be of the articulated, or fixed wheel base, or any other type, is the electric locomotive of the future; the halves, of course, of an articulated or bogie truck locomotive can, and probably should be unsymmetrical.

The authors have made one statement to which I must take exception, and that is that from an operating standpoint the railway man would like to have one locomotive which will handle at the desired speeds the heaviest freight and the fastest limited passenger trains. That statement can hardly be intended to be accepted in the fullness of its meaning. While it may be true as to its desirability, if it were possible, in the matter of a steam locomotive, it is distinctly not true with an electric locomotive, because the multiple-unit system which I introduced some twelve years ago has made possible any desired combination of locomotive units under a single crew. But what I would call to your attention is the fact that under some conditions it is highly desirable to consider the possibility of a locomotive which will be interchangeable for freight and passenger service for certain *fixed units of trailing load.* For example, it may be desirable, with certain limiting mountain grade conditions, to have a locomotive which can operate, say, 400- to 450-ton passenger trains at one speed, and a 500-ton freight unit at half that speed, and then to consolidate these locomotives as desired according to the train make-up. It can be admitted that theoretically this is not the most economical plan on which to build locomotives per se, but the alternative, of course, is to build electric locomotives for passenger and freight service of distinct characteristics and sizes, and without interchangeability of parts. Now on most of our mountain grade divisions we have stretches of single track operation, with frequent sidings, to take care of opposing slow and fast freight and passenger traffic. Every single-track railroad, no matter how frequently it is equipped with sidings, is a difficult road to operate, especially if the traffic is heavy. On account of varying grades it is the practice when using steam locomotives, and it will be so with electric equipment, to add to and drop off locomotives as may be demanded by the varying duty, but in any case idle movements of locomotives is a thing to be avoided, as far as possible, because locomotive movements cannot oppose traffic without affecting materially the whole movement of through freight or

passenger service on the line for a considerable period. Therefore if a locomotive can, without too great cost, be made available for interchangeable service, that is a desideratum to be seriously considered. It may result, of course, in a somewhat larger powered machine than is strictly required in the freight service, and a little heavier one than required for passenger service, but there will be a less total number because, instead of having two kinds of locomotives for each of which there must be reserve equipment, there will be only one kind, with a less total reserve equipment.

Another thing, it is cheaper to build a locomotive of a certain capacity than to build two of half power. The cost does not increase in proportion to the capacity. Another fact to be remembered is the importance of being able at any portion of the line to pick up or drop off a locomotive which shall be equally available for passenger or freight service.

I do not intend to take further time, but I want to emphasize two points. I am opposed to the idea that a very high center of gravity is vital to a successful electric locomotive. The idea has been handed down to us by our steam friends, and it has certain advantages. They cannot for many reasons get along without it on steam machines built for high speed. I also wish to emphasize the practical importance of sometimes having locomotives interchangeable for unit freight and passenger loads, as conditions may dictate the absolute necessity for such interchangeability.

A. H. Armstrong: In my opinion Mr. Sprague has not put the case too strongly in insisting upon the necessity of having freight and passenger locomotives interchangeable on mountain divisions where the maximum speeds are necessarily low. The weight of passenger trains may reach 600 tons trailing load and freight trains from 1800 to 2500 tons trailing load. It is desirable to move a train with a single locomotive unit if possible, but where grades approach two per cent on the better class of mountain divisions and even higher than this on some lines located before the requirements of modern freight traffic were thoroughly appreciated, it becomes necessary to consider two or more units per train in order to provide the draw bar pull required.

It is entirely feasible to consider an interchangeable type of locomotive running full speed with 600 ton passenger train units and half speed with a somewhat greater freight train load. A passenger train could be handled by a single unit while two or three units may be required with freight trains weighing two or three times as much.

The ratio of speeds, passenger and freight, may be taken at about 2 to 1 on mountain divisions, so that interchangeable locomotives of a uniform type offer a great advantage to the operating department on such grade sections as demand the use of helpers. Should such a uniform design of locomotive be

adopted for passenger and freight service, a difficulty is removed with electric locomotives which is not experienced with steam helpers. The electric locomotive operates to best advantage at one or two speeds only while the steam locomotive can give its full horse-power output at nearly any speed, and hence is adopted to act as helper to either a passenger or freight train, working efficiently at the operating speeds of both.

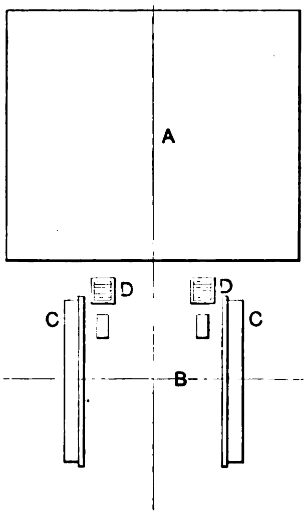
I think therefore that the matter of interchangeability is one of very vital importance and one that will be thoroughly appreciated by the operating department.

G. M. Eaton: Mr. Batchelder, in discussing this paper, was pleased to call it a mechanical paper. I wish to give you the reason why it seemed best to make the paper mechanical. In discussing Mr. Gasche's paper on Wednesday night, Dr. Steinmetz stated that in mill work the service, while far more severe than railway work, was a definite service. Now, in railway work, we find that the service of the motor from an electrical stand-point is very definite, and can be calculated to quite a degree of nicety, but we are confronted with an entirely different problem in calculating the mechanical stresses resulting from the negotiation of rails at high speed. This service produces maxima on the structure of the locomotive which are very hard to determine accurately. We can take a single rail defect, and assume all the conditions necessary, such as a known dead weight on the rail, spring-borne weight on the journal, speed of locomotives, etc., and under these conditions, we can work out a close solution of the stresses resulting on the framing. Unfortunately, however, when the locomotive strikes the first soft spot in the track, the conditions which are met are sure to be different from the conditions which were assumed in the calculations. We have then a nice set of figures, but the only real gain consists of the clearer conception, in the mind of the calculator, of what takes place in negotiating track of the particular characteristics assumed. This again is only the first step, as we must then consider the phase in which the various track irregularities occur, and the possible combinations with which we are confronted are legion. The application of exact mathematics is therefore impracticable in determining the precise dimensions of any given locomotive frame. Designers of electric locomotives must devote much study, however, to the means for minimizing the mechanical stresses on locomotive framing, and on track construction, and for this reason the paper under discussion is largely mechanical.

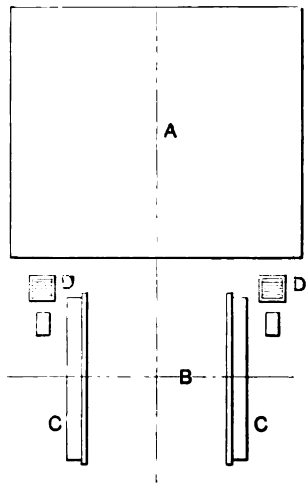
Mr. Batchelder stated that the weight dead on the axle was not productive of track destruction, so long as this weight was not in rotative unbalance. An examination of track maintenance on high speed interurban lines where dense traffic exists, shows room for improvement, and considerable experimentation is being carried out by some large operators' with a view to reducing the dead weight on rolling stock of this class.

Mr. Batchelder stated that the transverse distance between the semielleptic springs is of more importance than the height of the center of gravity. If this theorem could be substantiated it would constitute a severe arraignment against a low center of gravity locomotive with outside frames and a broad spring base. I wish to take exception to this theorem, however, for two reasons. Sketch No. 1 shows a locomotive with inside frames, and sketch No. 2 a locomotive with outside frames.

In each case, *A* represents the spring-borne parts of the locomotive, *B* the axle, *C C* the wheels and *D D* the springs. We agree at once that the arm with which the springs resist the swinging of the spring-borne parts is longer with the springs



Sketch No. 1



Sketch No. 2

outside of the wheels; but, referring to Mr. Batchelder's illustration, you will note that as the locomotive has been laid out the advantage of the inside frames, namely, the short transverse spring base, has been very largely sacrificed by the short stiff spring. This is not inherent in the design, but attention is called to it to show that we must go further than the spring location, and must examine the spring characteristics. If the springs are designed with greater flexibility, then with outside frames, the desired angular displacement of the mass of spring-borne parts can be secured. This greater flexibility will mean somewhat heavier springs, and to that extent a heavier locomotive; but in the locomotive shown by Mr. Batchelder far too many sacrifices are made in order to gain the lighter spring. When countershafts and connecting rods are added, introducing reciprocating stresses, I am convinced that too much has been spent in payment for a narrow spring base.

The locomotive as shown has the great advantage of having the minimum amount of rotative masses tied together, that is, each driving axle has its own motor, and if the wheels on one axle wear a little faster than those on the other, it is not necessary to machine all the wheels. This seems to be the chief advantage of the design as shown.

The second reason for taking exception to Mr. Batchelder's statement, though this reason is of first importance, is that the swinging of the spring-borne parts is resisted first by their own inertia, and second by the springs. The springs cannot act until after motion has actually started, and when the center of gravity is close to the point of side restraint, the blow on the rails will have been delivered, and whatever mischief is going to occur will have taken place before the springs have a chance to get in their work. It is, therefore, of paramount importance to secure the maximum operative vertical distance between the center of gravity of the spring-borne parts, and the point at which the transverse blow is delivered to the spring-borne parts, and any other considerations, such as narrow or broad spring base, are entirely secondary.

Mr. Batchelder also remarked that the dead weight in steam locomotives designed for switching service did not produce harmful effects on the track. In studying electric switching service, if we set up as our ideal the track maintenance that is involved under steam operation we are looking at the problem from an erroneous standpoint. The maintenance in steam operated yards is heavy, but it is something to which operating men have become accustomed. They expect it, and they certainly get it. In considering the electric locomotive, we must remember that there is no incentive to electrification if we cannot beat the steam locomotive. We must beat them at their own game, or we cannot make good.

Referring to Mr. Sprague's remarks, I like the phrase that the locomotive and the track are in a state of matrimony and cannot be divorced. We can in fact carry the comparison a little further. We are led to believe that the compromise in many matrimonial relations is entirely one-sided, and in our American locomotive designs, we make the locomotive so rigid that all the compromising in the horizontal plane must be done by the track. This is not a fair proposition. In this connection I want to make a plea for plate frames on electric locomotives. We have not come to it in this country, but it is being done very successfully in Europe. They have frames which will yield, and which will take their share in the horizontal plane, and this results in a reduction of track maintenance. In this country the track maintenance, that is, the maintenance of rails, ties, culverts, and bridges—runs from about the same as rolling stock maintenance to as much as twice rolling stock maintenance. It is quite generally conceded that much more than half of the track destruction resulting from the passage of a train can be charged up to the locomotive. We can, therefore, imagine a locomotive

in which maintenance is increased a little, while the maintenance of the entire system is very materially decreased and this with greater safety of operation. What seems to be necessary then is for the railway organization to be under one supreme head who will say to the heads of the various departments: "Now, gentlemen, get together". In this ideal organization, the various departments are not working each for themselves, but all are working for the railroad as a whole. This is the ideal to which large railroad organizations just the same as any other large organizations should bend.

Referring further to Mr. Sprague's remarks on center of gravity, he said, that it was entirely possible in his opinion to build a low center of gravity machine for successful high speed operation. I agree with Mr. Sprague that it may be possible. I do not believe, however, that it has ever been done.

Mr. Sprague referred to the Greenwich wreck on the New Haven Road, and I should like to add a little to his remarks. Mr. Storer and I left the Grand Central Station on the train immediately following the one which was wrecked, and arrived at the scene of the wreck within about 20 minutes of the time it occurred. The most impressive feature of this wreck to me was the way in which the locomotives held the train in tension after the derailment occurred. Instead of going through the bridge as a steam locomotive would probably have done, they carried every car safely over the bridge, although nothing but the steel bridge girders was left after the last car passed. The motors slid on the rails, so that the wheels could not cut deeply into the ties, and it was not until a Pullman truck had skewed around, causing its car to turn on the side, that any buckling of the train occurred. After this coach overturned, there was sufficient inertia in the locomotives to pull out a car drawhead and the locomotives and several cars ran 300 ft. further before stopping. The locomotives were then put on the rails and proceeded to the power house by their own power.

The number of deaths that have been caused by steam locomotive derailments, would have been materially decreased if the locomotives had been fitted with skid bars which would perform the duty so well fulfilled by the motors at Greenwich. A locomotive with high center of gravity and equipped with skid bars, would combine the desirable features of minimum derailing tendency, together with a minimum of destruction due to a derailment caused by a track defect.

N. W. Storer: Mr. Sprague took exception to our statement in the early part of the paper, to the effect that the superintendent of motive power and the superintendent of the operating department, would like, if possible, to have an absolutely interchangeable locomotive. He denied that statement, and then proceeded to prove it was absolutely necessary to have an interchangeable locomotive. I believe that the statement in the paper is correct; I believe fully it would be desirable to have an interchangeable locomotive if it is commercially possible. That

is the whole point in the matter, and it is not necessary to try to prove at all that such a thing is desirable. If the operating man can afford to spend, or if the company can afford to spend, a large percentage more for locomotives for operating the trains over the road under a system which will make it necessary to have only one type of locomotive on the road, then it is commercially possible and quite practicable.

Elmer A. Sperry: The Institute is to be congratulated upon so timely a paper as that of Messrs. Storer and Eaton dwelling as it does upon the detailed construction of the heavier class of locomotives, especially with reference to the more general mechanical arrangement, distribution of weights, methods of power transmission, etc. In connection with mechanical design it might be well to point out one other phase, namely, its bearing upon the development of draw bar pull, upon the apparent adhesion and also upon tractive effort.

Many observations have been made in connection with slipping of drivers of locomotives, and of trucks, especially those employed in heavy service. There has also been considerable discussion with regard to the internal stresses and especially the redistribution of weights upon drivers under conditions of developing maximum draw bar pull.

In 1888, the writer drew attention to the very large apparent difference between the total coefficient of adhesion as between separately driven and coupled axles. There were cases where the latter showed repeated and continuous evidence of developing some 40 per cent more draw bar pull than the former. An investigation was started to ascertain the nature and extent of the difference between these two types. As the work progressed, it was at once seen that perfectly concordant results were being obtained and that a law governed the case which could be expressed by formula which was afterwards found to be a correct expression of the facts. This formula may be stated as follows:

Maximum draw-bar pull with independent axles.

$$P = \frac{W\phi}{20\frac{h}{b} + 1}$$

in which

P = the draw bar pull (maximum).
W = the weight (total) of locomotive in pounds.
ϕ = the coefficient of adhesion.
h = the height of bolster or drawhead.
b = the wheel base.

With coupled axles, either by rods or gears, the maximum pull is simply $W\phi$.

It will be observed from the foregoing that in any truck where the bolster height is *equal* to the wheel base, we are obtaining about 66 per cent of what we are really entitled to, and the coupling of the drivers will give us an increase of tractive effort of *one-half more*; in trucks where the wheel base is 1½ times the

bolster height we are obtaining 75 per cent of what we are entitled to and the coupling would yield one-third more; and in trucks where the wheel base is twice the bolster height we are obtaining 80 per cent and the coupling would yield 25 per cent more. We thus see that this is not at all an insignificant matter but one of large magnitude.

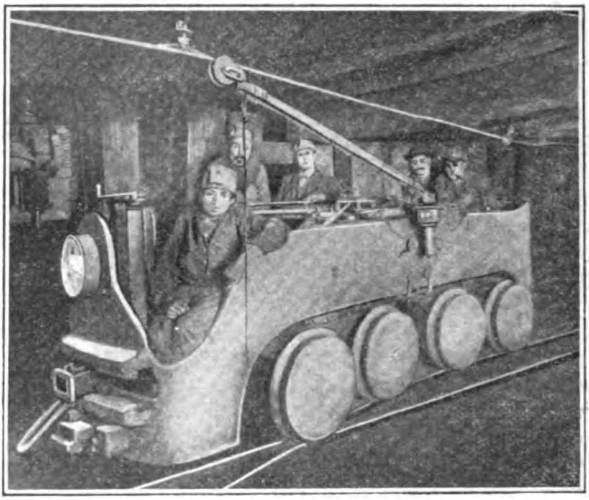


FIG. 1

In 1890 the writer was engaged in manufacturing locomotives in which this principle of coupling the drivers to obtain maximum draw-bar pull was carried out to an extent quite unique at that time, and even since, namely, the class of locomotives

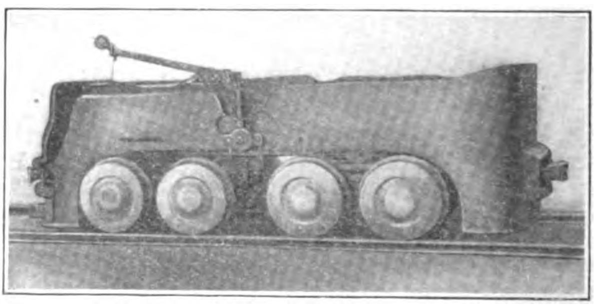


FIG. 2

having four axles or eight drivers connected with a single motor. See Figs. No. 1 and 2.

In June 1892 the writer presented a paper before this body at its annual meeting in Chicago referring to experience and results

obtained with this class of locomotive under service conditions. See TRANSACTIONS for 1892, Vol. IX, page 397.

The drivers of the locomotives referred to were in groups of four upon each of the two trucks and were arranged so they could swivel in taking the short radius curves present in mines. The heavier type of these locomotives often work on curves as small as a 10-ft. radius. In this connection it is interesting to note that these locomotives were not only designed for heavy service but they were successful in a marked degree in accomplishing this purpose.

Fig. 1 is a photograph of a locomotive which was installed 1890 or 1891 and Fig. 2 is a photograph of the same locomotive after it had been continually in service for some eighteen years or more. This locomotive seems to be unique in that it has been in continuous service for a longer period than any equipment of which I am aware. In any event it is a noteworthy instance of an apparatus standing up under service which is acknowledged to be severe in the extreme.

More recently some interesting tests have been undertaken with a view to determining by experiment to what extent the redistribution of weights occurring upon two axle trucks affect the apparent adhesion. To this end, two locomotives were tested with a draw-bar pull at two heights above the rail, each locomotive, being 12 tons and motored to the point of easily slipping its drivers. The log of the test is as follows:

SLIPPING TESTS

14.5 in. height drawbar above rail

Amperes	Drawbar pull at slipping	Drawbar pull in per cent of weight
415	7000	29.15
412	7200	30
435	7500	32.3
	Average. . .7316	30.48

Drawbar height 9¾ in. wheel base 48 in. —33 in. wheels, steel tire.

Amperes	Drawbar pull at slipping	Drawbar pull in per cent of weight
375	7100	29.15
410	7300	30.4
450	7500	31.3
418	7300	30.4
445	7700	32.15
445	7700	32.15
449	7500	31.3
405	7100	29.6
	Average. . .7388	30.71

Tests were also made on a 12-ton locomotive equalized with the first as to total weight and having independently driven axles. Slipping took place at a drawbar pull of about 5250 lb.

with the 9.6-in. height of drawhead and 4850 lb. with 15.5-in. height of drawhead, averages of all the tests being as follows:

Height of drawbar above rail	Amperes	Drawbar pull at slipping	Drawbar pull in per cent of weight
15.5 in.	312	4950	20.6
9.6 "	334	5250	21.85

The average percentage of adhesion at point of slipping in the case of coupled drivers is about 45 per cent in excess of that in the two-motor equipment; same standard steel tires and identical rails were used in each case.

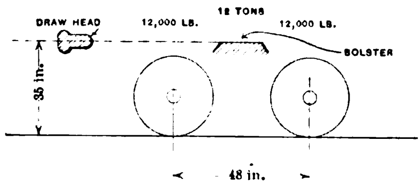
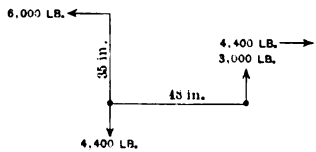


FIG. 3



	BACK	FRONT
	12,000	12,000
	+ 4,400	- 4,400
WHEEL PRESSURES	16,400	7,600

MAX. D.B. PULL	AXES COUPLED	6,000 LB.
" " "	AXES INDEPENDENT	4,500 LB.
INCREASED PULL DUE TO COUPLING,—		33⅓ PER CENT

FIG. 3a

This indicates that the coupling of drivers effects favorably and to quite an unexpected extent the apparent coefficient of adhesion.

The nature of the shifting or redistribution of the weights as between the two axles upon an ordinary car truck or two-axle locomotive is very much greater than has been usually understood by builders of independently driven axle equipments, and the loss of capacity incurred has been generally underestimated. Ordinary practice with double motor street car or interurban trucks by the simple act of coupling would be entitled to between $\frac{1}{3}$ and $\frac{1}{4}$ more total tractive effort than is obtainable with independent driving.

When a locomotive or truck is pulling a load, there are only

two forces acting, which are external to the locomotive and independent of any internal forces. These two are the pull at the draw head or the bolster and the opposing pull of the wheel rims against the track. If these two forces are not in the line of travel, a tilting action will be produced, tending to elevate one pair of wheels, reducing the weight on them, and transferring additional weight to the other pair. As the draw head is always at some distance above the rail surface, there will always be shifting of loads on the drivers, due to the tilting effect of the draw bar pull.

Tests were undertaken to determine just the extent of this redistribution by apparatus shown in Fig. 4, namely, the front axle of a four-wheel locomotive weighing 12 tons, 48-in. wheel base, was placed upon rails *B* secured to a platform scale *A* the rear axle being placed upon the rails *C* and as between the pairs of rails the link *E* was supplied to take up the reaction without interfering with the action of the scale. The draw head *H* was rendered adjustable as will be seen in the table and was

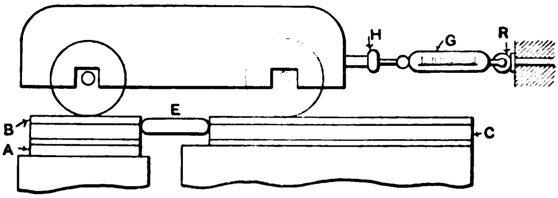


FIG. 4

coupled with a rigid point *R* also adjustable as to height by a dynamometer *G*. The log of this test is as follows:

Draw bar		Decrease in load upon front axle		
Height	Pull	Observed		Computed
			Probable limit of error in readings	
12 in.	6060	1520	160	1515
14 "	6100	1800	170	1780
16 "	6080	2000	210	2030
18 "	6010	2300	140	2280
20 "	6045	2700	180	2520
24 "	6030	3150	160	3015
35 "	6020	4500	190	4460

To give the foregoing analysis some definiteness, consider an example of a 12-ton locomotive with a 48-in. wheel base, the draw-bar being 35 in. above the track, adhesion taken at 25 per cent, we find that when the draw-bar pull is 6,000 lb. the weight upon the rear axle is 116 per cent in excess of the weight upon

the forward axle. This is illustrated graphically in Fig. 3. Fig. 3*a* shows the force diagram, followed by deductions therefrom.

Summing up then, an electric truck or locomotive having two axles which are driven by independent motors has the weight on the forward axle reduced by an amount proportional to the drawbar pull; the pull it can exert is limited by the tractive effort of the least adhesive pair of wheels; because if one pair of drivers slips the other pair slips also.

If the two pairs of wheels be coupled together it is clear in case slipping occurs all the wheels must slip together. Therefore, the shifting of the weight due to the tilting effect of drawbar pull, does not decrease the maximum drawbar pull for although one pair of wheels gives a less pull than the other pair, the sum of the two is always constant, and since they must act together, the maximum draw-bar pull remains constant regardless of the tilting effect. The connecting of the wheels serves to automatically distribute the power of the driving motor between the two pairs of wheels in direct proportion to their respective adhesion to the rails.

All that has been said about tractive effort is equally true and quantitatively so as regards increased capacity for breaking or de-energizing the masses; here the shifting of weight loads the front axle and lifts the rear axle, allowing it to slip at much lower brake pressures than are easily permissible with coupled drivers.

Frank J. Sprague: Replying to Messrs. Eaton's and Storer's closing remarks, I am glad to note that it is acknowledged that it is "theoretically possible" to build a low center of gravity locomotive to run at high speed, and the possibilities of a flexible frame are suggested. That suggestion is quite in line with a thought of my own, and it is possible that in connection with some form of a linked truck construction, properly restrained or damped, there may be found one acceptable of solution of satisfactory locomotive construction.

Mr. Eaton in his reference to the New Haven wreck somewhat unwittingly and naively introduces a new element of discussion in locomotive design which gives emphasis to the statement that all such must necessarily be a compromise. He states that had the derailment occurred with steam locomotives the results would have been appalling, but that, as constructed, the axle-mounted motors helped to hold the locomotives in line with the track after the wheels had left the rails; in other words, motors with their axes coincident with axle axes prevented a disaster which would have been certain with motive power carried with a high center of gravity. The query naturally arises: What would have been the result had electric locomotives of the more recent vogue been used, that is, those with motors well up in the cab, driving by side and connecting rods through intermediary jack-shafts?

I will have to correct Mr. Storer's statement. He said that

I took exception to the author's statement to the effect "that the superintendent of motive power and the operative department would like, if possible, to have an absolutely interchangeable locomotive," and that then, while denying this statement, I proceeded to prove that it was necessary. The quotation is in error. I took exception to the statement as actually given in the author's paper, that "from an operator's standpoint it would be very desirable to have one locomotive which would be capable of handling at the desired speed any train from the heaviest freight to the fastest limited." I stated that this was not desirable, but that on certain roads, like some mountain divisions, it might easily be desirable within the ranges of speed which were required to have an *interchangeable locomotive for a "given unit weight,"* which would impose the same maximum drawbar pull, and to then combine these unit locomotives as required under multiple unit control. This is quite another thing, and its application becomes apparent when the makeup of passenger and freight trains in such service is considered.

Discussion on "Power Economy in Electric Railway Operation Coasting Tests on the Manhattan Railway, New York". Jefferson, N. H., July 1, 1910. (See Proceedings for July, 1910.)

(Subject to final revision for the Transactions.)

John B. Taylor: I wish to ask Mr. Putnam if the motormen have found any way to beat this clock. I have not studied the diagram very carefully, and wonder if by turning on the power and turning it off again immediately at a station, it would be possible for the motorman to make the clock record during the time of the stop.

A. H. Armstrong: The problem of reducing energy consumption of a train is now pretty well understood, and I am very glad to see that active steps are being taken to keep a record of the performance of the motorman. It is well known that rapid acceleration decreases the amount of power consumed in frequent stop service, but in connection with that I would ask Mr. Putnam if he has noticed any increase in the ragged appearance of the substation load curve, and whether the more rapid acceleration used has called for any appreciable increase in substation and distribution system capacity.

Rapid acceleration may be carried too far where the service is infrequent, and it is possible to approximate its benefits without unduly increasing the maximum demand per train by resorting to a very high rate of acceleration in series and a lower rate with the motors connected in parallel. The advantages in so doing are two fold. It affords a quicker get away from the station with a corresponding abrupt angle of the speed-time curve, and reduces the maximum demand of the train and the motors in multiple running where it will most effect the distribution system and the operation of the motors themselves.

N. W. Storer: This paper has been of great interest to me. It is certainly a great satisfaction to feel that railway operators are at last beginning to realize the necessity for careful instruction of their motormen, and the saving that can be effected by proper operation. I believe that ignorance of the correct theory of operation is at the bottom of a large part of inefficient operation of electric railways. I have great faith in the motormen of interurban railways, and believe that if they are properly instructed, they can usually be relied upon. The great trouble is not so much with the motormen as with the managers of the road.

The installation of the "coasting time clock" described by Mr. Putnam will automatically instruct the motormen as to the best method of operation, and will be a good check on them as well. This method seems to me to get at the root of the matter much more quickly than the use of the wattmeter. It has the great merit of giving the men practically one point to look out for, and if this one is kept constantly in mind, the efficiency of operation will undoubtedly be high.

L. B. Stillwell: The facts set forth in the paper which Mr. Putnam has presented are an excellent illustration of what may be called effective team work between the consulting engineers and intelligent, alert operative men. I quite agree with Mr. Putnam's suggestion that at times we are hard on the manufacturers, in asking them to do almost the impossible. Of course, it is right to obtain the best that is reasonably practicable, but in doing that we may be overlooking many opportunities for economy in our own particular province in the field of construction and operation. The value of the economies effected by the introduction of this coasting clock on the Manhattan Elevated Railway system in New York is extremely striking. The power bill of that division of the Interborough Rapid Transit Company approximates $4,000 a day. A reduction of twenty-five per cent is about $1,000 a day, and you can see what that means. That has been accomplished by the joint work of the consulting engineers and operating men. The particular device used is due to the operating men, who have very intelligently developed something which is effective with their motormen. They propose to establish a system of premiums, which will further stimulate the attention and effort of the motormen.

Referring to Mr. Armstrong's question, the effect has not been to increase the average acceleration, but to bring it up to what it was intended to be, not beyond what the substation was designed for, but to the standard of economy which the engineers originally intended in laying out the plant. The desirable coasting period, as determined theoretically is thirty-five to forty seconds, the actual performance without the clocks being only twelve. This condition of affairs required the introduction of a clock. The clock has brought the performance up to the economic standard set by the engineers.

Wm. McClellan: There is a point to which he refers, that I would emphasize in connection with Mr. Putnam's paper, and that is the question of lengthening out the coasting time at the end. My own experience is that it is difficult to get a motorman to brake a train in what you might call the theoretically efficient manner; in other words, the habit which the motorman has of putting on the brakes long before they need be put on, then letting them go, then applying them again, and letting them go again, etc.; and I think that this is a loss which the measuring of the coasting time would eliminate more effectively than any other power consumption on the train which is measured. The saving can hardly be estimated, but is very great, which could be secured from the elimination of this habit of the motormen of applying their breaks and releasing them without occasion. That point is referred to in the paper, but not emphasized.

Frank J. Sprague: The striking facts set forth by Messrs. Putnam and Stillwell are a somewhat tardy contribution to the efficiency of coasting and quick acceleration which have been

advocated since the South Side Elevated road in Chicago was first operated electrically. No reference has been made to automatic acceleration. When developing electric elevators and establishing the secondary control of controllers, I quickly realized that the personal element of a man was a small thing to rely upon for perfect service; that to get even torque on motors, reasonable strains on apparatus and a proper consumption of the supply of electricity, whether from a battery or a dynamo, the movement of the controller should be automatically accelerated and controlled. In the case of the South Side road, where the first multiple trains were installed, every main controller was fitted with a throttle which permitted the controller, under control of the master switch, to automatically accelerate to either series or multiple position, at a rate determined by the amount of current passing through the motors.

Economy of operation between stations depends primarily on two things; first, the quickest, safest and most comfortable acceleration, and second, the maximum safe and comfortable braking. The necessary amount of coasting is determined by the relation of these two. Automatic acceleration, now used on most recent equipments, performs the first function. That, however, is not enough, for while it removes from the motorman the personal element in starting his train, he is still privileged to continue to accelerate, coast for a short distance, and meddle with the brakes in any way he sees fit. The introduction on the Manhattan Elevated Railway of the coasting clock, to check the operating engineers on that road by determining the coasting time, is an excellent method of insuring a fuller measure of the value of coasting on a railroad. Mr. Stillwell has pointed out that it means saving $1,000 a day in power supply in the case of that one road. It also means something else, for referring to the figures given in Mr. Putnam's paper, I estimate that it would have effected on the Manhattan Elevated Railroad a saving of about 5,000 kilowatts in initial equipment, which represents a capital cost of anywhere from $500,000 to $750,000.

L. B. Stillwell: The figure I mentioned, viz., $1,000 a day, was meant to include interest on the capital cost as well as the car operating cost.

N. W. Storer: There was one point I neglected to mention in my previous remarks, and that was to speak of the series operation which Mr. Armstrong brought out so well. I agree with him heartily, and want to mention that it is perfectly possible to arrange the control, as has been done in some cases, to accelerate at a high rate in series, and any other fixed rate in parallel, so as to get the automatic acceleration which certainly is most desirable.

G. H. Hill: The acceleration portion of the speed-time curve is undoubtedly the most important with relation to the comfort of passengers and the economy of power. As Mr. Sprague pointed out, the adoption of automatic control removes this

element from the influence of the motorman. As Mr. Storer mentioned, and as in operation in different places, this can be accomplished either at a constant current per motor, or at different predetermined rates in series and in parallel. That leaves only two elements of the curve which may be varied according to the judgment of the motorman.

If there were developed a practicable system of automatic braking (that is, a system wherein the braking effort is applied automatically as some function of the speed), the proper amount of coasting would, for a given schedule, take care of itself. Such a system of braking is somewhat complicated, and has not to my knowledge been used. With heavy trains, operated at speeds higher than now usual in a service requiring frequent station stops at a high rate of braking, it may possibly become a desirable or necessary feature.

Mr. Putnam's apparatus aims at the desired result by checking the coasting period, so as to induce the motorman to reproduce as nearly as possible the proper predetermined run cycle. The results seem to fully justify the complication and expense incident to its use. The arrangement of circuits and apparatus illustrated can I think be somewhat simplified and perhaps improved so as to be self contained and quickly applied to any car. The scheme certainly seems more practicable than the use of recording wattmeters, which are sometimes advocated for a similar purpose.

H. St. Clair Putnam: Several questions have been raised in the discussion of this paper which I will take up as briefly as possible. Mr. Taylor has inquired what precautions have been taken to prevent the beating of the clock by the motormen. This subject has been carefully considered by the designers. The diagram of the connections used for measuring the time of coasting is given in the paper. All electric contacts and magnets used in the operation of the clock are placed inside the case excepting the contacts which are made and broken by the operation of the brake cylinder. The latter are placed beneath the car. It is impossible to cause the clock to register coasting time without manipulating these contacts and at the same time having the controller handle in the second position or beyond, so that the motors as well as the clock will receive current. This is practically impossible for the motorman to accomplish. In addition to these precautions, in the case of the Manhattan Elevated system, the clocks are placed on the trailers, entirely out of reach of the motorman.

Mr. Taylor suggests that it might be possible for the motorman to beat the clock by turning power on and then off again immediately during the time of stop. While this, of course, is physically possible, yet it is impracticable because the actuating current is taken from the second point of control, which the motorman cannot reach without moving the train, and if he attempts to hold the train with the brakes, the clock is im-

mediately stopped. If he can coast into the stop the clock will continue to register, but as such a stop results in the largest possible return for the energy used, owing to the energy otherwise lost in braking being used to move the train, the motorman is entitled to all the credit he can obtain in this manner. Practically it will be impossible for the motorman to make such stops and maintain the schedule, and in most cases it is practically impossible for him to make a stop without using his brakes, or stand still with his brakes off, because of grades.

Mr. Sprague, Mr. Armstrong and Mr. Storer have commented upon the subject of the reduction made in the amount of energy required by increasing the rate of acceleration. This has long been recognized. The possibility of its accomplishment in electric operation, and especially in multiple unit operation, is one of the most important advantages obtained in electric traction. The amount that this acceleration can be increased is limited, in any particular case, by the capacity of the equipment provided. As Mr. Stillwell has pointed out, however, it is not the function of this clock to increase the acceleration over the amount for which the equipment has been designed, but to obtain in practice the acceleration that was contemplated by the engineers in selecting the electrical equipment for the system, including motor cars, substations, feeders and power house. As all operating men know, and as our tests of the Manhattan Elevated show, the motormen do not attain in practice the acceleration that they are instructed to use. This clock has demonstrated that under the guise of increasing the coasting time, the advantages of rapid acceleration are forced upon the motormen, and the desired result attained.

Mr. Sprague and Mr. Hill have called attention to the benefits to be derived from automatic acceleration and that this would take one of the elements of the speed-time curve out of the control of the motorman, and assist in accomplishing the results desired. This is true, but one of the most important factors in the operation of the Manhattan Elevated system which resulted in increasing the amount of the coasting obtained in our tests was not so much an increase in the rate of acceleration, as improvement in the manipulation and handling of the trains.

This is illustrated by the fact that since the clock has been installed the motorman coasts up slowly behind a preceding train, when delayed by the train in front, instead of coming up full speed and then applying the brakes and coming to a stop as is usually done. This results in a material reduction in the energy used. Furthermore, the motorman soon finds that he can increase the amount of coasting and still maintain his schedule if the stops can be cut down, so he gets after the rest of the train crew to cut the stops as short as possible. As most of the crew are candidates for promotion, they are forced to respond.

Mr. Hill has also called attention to the possibility of auto-

matic breaking, and Mr. McClellan has emphasized the importance of braking. If automatic braking were possible of accomplishment in a practical manner it would be most desirable. The proper braking of a train on such a system as the Manhattan Elevated is the most difficult part of the operation to obtain from the motormen, as judgment, skill and experience are required. Such an automatic device, if perfected, must of necessity permit the motorman to increase or decrease at will the rate of braking fixed by the automatic device, so that he can make his proper stop at the station platform. There are many practical difficulties in the way of the attainment of this result, though I will not say that it is impossible of accomplishment. Experience gained on the Manhattan system, however, has shown that the installation of the coasting clock has resulted in a radical improvement in braking as well as in acceleration, and that with this device, the theoretical speed time curve as used by the engineers in designing the equipment of the road can be closely approximated in the average results obtained, while some of the motormen by careful handling of their trains obtain even better results.

Mr. Armstrong and Mr. Storer have suggested that a rapid acceleration can be used in the series position, and a reduced rate in multiple, with the result that a fair average rate of acceleration can be obtained without compelling the substation to take care of such high peaks as would otherwise result if the same running time were made by using a uniform straight line acceleration for both control positions. There are many advantages in this method of operation, especially for interurban roads where the substation capacity is limited, and the trains infrequent. With the short headway used on the Manhattan system, however, the advantages of such a method of operation largely disappears. As already has been pointed out, the strength of gears, motor capacity, and the comfort of passengers, limit the practical rate of acceleration that can be used. In all cases, if this rate of acceleration can be employed in series, the average of both the power and energy required will be reduced by using the same rate of acceleration in multiple, for the simple reason that in a large system such as the Manhattan, all apparatus in the power house, substations and feeders can be operated at their heating and economical limitations, and any reduction in the energy used therefore results in a corresponding reduction in the apparatus required.

In the case of interurban roads and other roads of limited service, the improvement made in the operation and handling of equipment resulting from the installation of some such device as this coasting clock, might result in the ability to reduce the rate of acceleration used during the multiple period, with a resulting reduction in the average rate of acceleration, and a corresponding reduction in the peak load on the substation feeder system and power house, without reducing the scheduled

speed. This again, however, would have to be balanced against the cost of the increased energy used. In most cases, especially where the service and stops are frequent, the higher rate of acceleration usually will be found most economical.

P. A. Bancel: Mr. Putnam points out clearly the key to economical operation of heavy city railways by saying that "the energy absorbed in braking is the essence of the whole subject." One means of reducing the amount of energy lost in braking is to retard the speed of the train by causing it to climb a grade. By running a train up a slight grade as it approaches a station, and down a similar and equal grade as it leaves the station, an interchange of kinetic and potential energy is secured and corresponding saving in power obtained. The principle in-

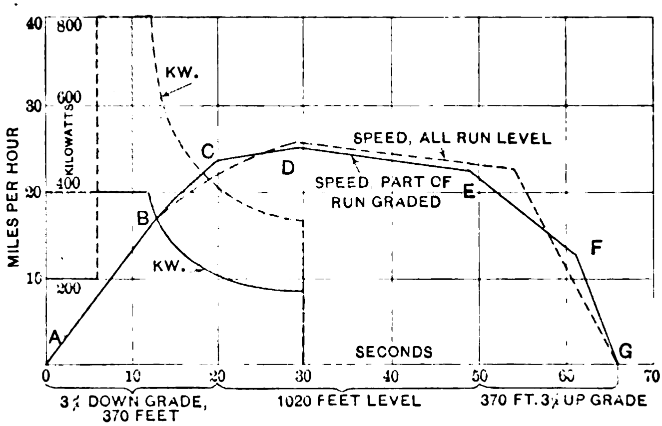


FIG. A.—*A-B*, acceleration due to gravity plus motors; *B-C*, acceleration due to gravity plus motors on motor curve; *C*, end of 3 per cent down grade; *C-O*, acceleration on level, due to motors on motor curve (resistance all cut out); *D-E*, coasting on level track, retardation due to train resistance; *E-F*, coasting on 3 per cent up grade, retardation due to gravity plus train resistance; *F-G*, braking, retardation due to brakes, gravity and train resistance.

volved is evidently similar to that employed with elevators, where counter weights retard or brake the speed descending, and assist the motion in ascending.

The saving produced by applying such a principle to electric railway traffic can best be shown by an example. Taking the train of Fig. 3, assume that the train leaving the station at time zero, is on a 3 per cent down grade. Since the force of gravity acting on the train is 154 tons, the accelerating force in the direction of motion will be $3/100 \times 154 \times 2000 = 9240$ lb. Now the force necessary to produce an acceleration of 1.33 miles per hr. per second (the acceleration of Fig. 3) is 18620 lb., as found from the well known expression, force = mass $\times$ acceleration. Since the 3 per cent grade is providing 9240 lb. accelerating

force, it is now necessary to obtain only 18620–9240 or 9380 lb. accelerating force from the motors of the train. This is approximately 50 per cent of the original force necessary.

If then a train of the same weight were equipped with motors of but half the capacity, and drew only half the current from the line, the same resistance acceleration would be obtained on a 3 per cent down grade. This line, *A B*, shown on Fig. *a* is therefore identical with that of Fig. 3 of the paper.

All the resistance being cut out, the motors accelerate on the motor curve. Assume now that the 3 per cent down grade lasts till the end of the 20th second. From the time that the resistance is all cut out at the 12th second, up to the 20th second, the train is also being accelerated by the component of its weight, 9240 lb., acting in the direction of motion. At any second the accelerating force along the motor curve is proportionate to the

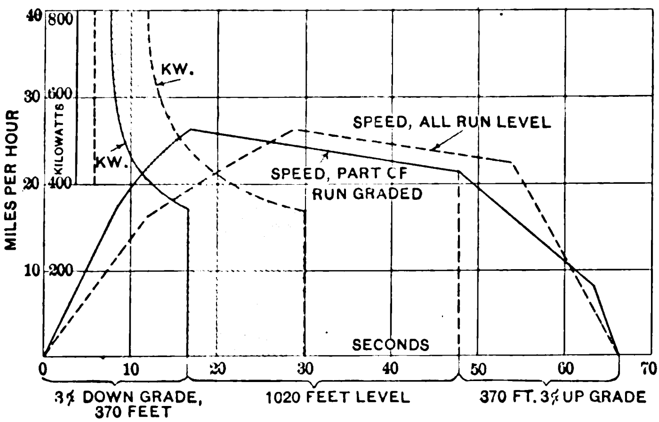


FIG. *b*

kilowatt input divided by the speed. Assuming that at any instant with the motor equipment reduced by half, the accelerating force due to the motors is also reduced by half, figures are obtained from which the accelerating curve from *B* to *C* and *B* to *D* was calculated. From *B* to *C* acceleration is due to both motor force and gravity, and the actual velocity at any instant was obtained from the acceleration, which in turn was derived from the total accelerating force at the same instant. This accelerating force has been seen to be the sum of the constant 9240 lb. and the variable motor accelerating force. The curve from *C* to *D* is the plain motor acceleration curve.

By assuming 3 per cent down grade for 20 seconds, followed by level track, it is seen that the speed time curve obtained coincides very closely with the original. The rest of the chart is constructed by following similar calculations. The line *E F*

is the braking due to the upgrade alone, while *F G* is that due to both the up grade and the actual brakes. The point *E* was determined by trial to make the area under *E F G* equal to that under *A B C D*. Thus the distances of up-grade and down-grade are equal. From the areas the actual distances are calculated as 370 ft., 3 per cent down grade, 1020 ft. level track and 370 ft., 3 per cent up grade. By assuming these distances, and grades, the whole speed time curve is made to coincide very closely with the original, so that their areas and therefore the total distances traversed in either case are the same.

The saving to be obtained by such a see-saw arrangement of grades has already been indicated. For the same rate of acceleration about half the kilowatt-hour input would be required, and only half the motor capacity would be needed. The kilowatt-seconds input saved where grades are used is shown by the shaded area and this is roughly ½ that originally necessary.. It is interesting to note that the time during which the brakes are applied and therefore the "energy absorbed in braking" is correspondingly reduced.

Fig. *b* is drawn to show the result when using the original motor accelerating force and motor equipment, with track profile similar to that for Fig. *a*. The total accelerating force is again increased by reason of the gravity component while the motor accelerating force is equal to that with the original train, so that the maximum speed is reached much sooner. The areas under the speed curves and therefore the distances traversed in both cases are approximately the same, and the saving in power is shown by the difference between areas under the kilowatt curves.

DISCUSSION ON "VECTOR POWER IN ALTERNATING-CURRENT CIRCUITS". JEFFERSON, N. H., JUNE 29, 1910. (SEE PROCEEDINGS FOR JULY, 1910.)

(Subject to final revision for the Transactions.)

C. P. Steinmetz: The standardization of vector notation in alternating current theory is of importance. Considering the difficulty which college students often have to get a conception of one method of vector notation, the existence of two methods, of which the one appears the reverse of the other, evidently is very regrettable. A standardization of vector notation would therefore be very desirable, if feasible. The difficulty is, that we are here in the field of applied mathematics, and in mathematics, the right of priority, and resulting therefrom an international method of notation, is generally recognized. Thus, whatever standard we select, must conform with the existing standards of mathematics, as it obviously would not be reasonable to expect all other sciences to change their notation to conform with our standards; and inversely, no action of ours could exclude from use in electrical investigations, methods which are standard in other sciences.

To explain the situation, we may for a moment discard all the various conventions of vector analysis, which have been proposed in electrical engineering, and go back to the starting point, the conventional methods of elementary mathematics, which the student brings with him when he enters the field of electrical engineering.

In analytic geometry we become familiar with the representation of geometrical figures, curves, etc., by rectangular co-ordinates. Then we learn a second method of representation, by the system of polar co-ordinates, in which the angle represents the independent variable, the radius the dependent variable. We find that the polar co-ordinate system is especially convenient and suitable for periodic functions.

Entering the field of electrical engineering, we meet in the alternating current a function of time, and naturally represent it graphically in rectangular co-ordinates, with the time as abscissae and the current, or voltage etc., as ordinate, by a wave line, the usual sine wave, as shown in Fig. 1, which is familiar to all, even the non technical men; or, if we happen to deal with a current which is not a sine wave, by a wave line of some other shape, for instance like Fig. 2. Such are the records given by the oscillograph.

Now we realize that the alternating current is a *periodic* function of time, and that periodic functions are more conveniently represented by polar co-ordinates. We thus plot the current wave in polar co-ordinates: the angle, ϕ in Fig. 3, is the abscissae of the rectangular co-ordinate representation Figs. 1 and 2, that is, the time t; the radius i is the ordinate, the current, voltage, etc. This gives us as the polar curve, that is, the representation in polar co-ordinates, of the sine wave Fig. 1, the

circle Fig. 4; the distorted wave of Fig. 2, that is, a wave differing from a sine shape, gives in polar co-ordinates a curve differing from a circle. Fig. 5.

Thus far we have followed the existing international convention of mathematics, and thus far therefore no occasion nor possibility exists for electrical standardization, but we follow the already existing and immovable standards of mathematics.

In many electrical problems, we can replace the distorted

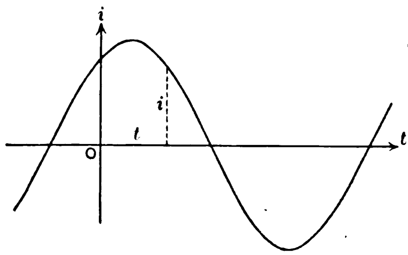


FIG. 1

wave, Fig. 2 respectively 5, by its equivalent sine wave. The polar circle, which represents the equivalent sine wave, is easily derived from the polar curve Fig. 5. It is a circle having the same area as the polar curve of the distorted wave, Fig. 5, and its diameter is the bisector of the area of curve 5. Thus the representation in polar co-ordinates lends itself very conveniently to the determination of the equivalent sine wave and the effective value of the wave. Irrespective of any further use in

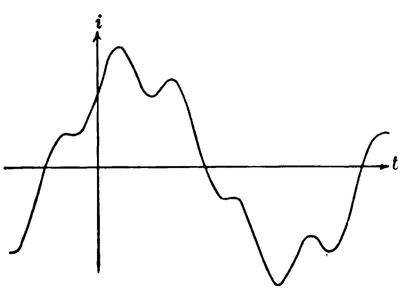


FIG. 2

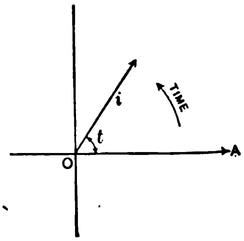


FIG. 3

vector analysis, the polar co-ordinate system of representation thus is largely employed for deriving the effective value of a distorted wave, and, with the increasing use of the oscillograph will be increasingly used. Thus, in working up oscillograph records, the curve given by the oscillograph (for instance Fig. 2) is replotted in polar co-ordinates (Fig. 5), its area measured by planimeter, and this area, divided by $\frac{\pi}{2}$, is the effective value of the distorted wave, or the value of its equivalent sine wave.

The circle, Fig. 4, thus is the representation of the sine wave, or of the equivalent sine wave of the distorted wave, in polar co-ordinates.

In those electrical problems, in which we do not have to deal with the instantaneous values, but with the current as a whole, we may omit drawing the circle, but merely give its diameter, $\overline{OI}$ in Fig. 6. Thus, as natural sequence of the standard methods

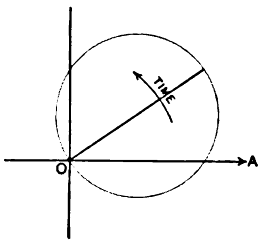


FIG. 4

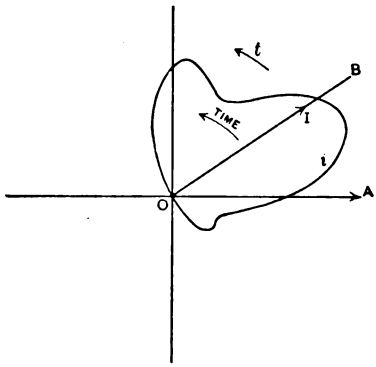


FIG. 5

of analytic geometry, we get in the diameter $\overline{OI}$ of the polar circle the vector representation of the alternating current, voltage, etc. The length $\overline{OI}$ then represents the intensity, its angle $A\ O\ I$ the time, at which the maximum value of the current occurs, that is, its phase. If then, in Fig. 6, $\overline{OI}$ current is a vector, $\overline{OE}$ a voltage vector, Fig. 6 completed by drawing the polar circle with OI and OE as diameters, gives in Fig. 7

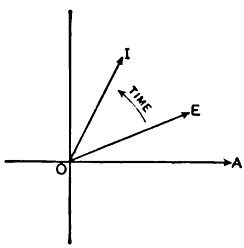


FIG. 6

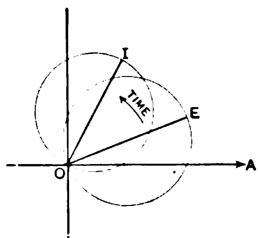


FIG. 7

the current wave i, and the voltage wave e in polar co-ordinates. As shown in Figs. 6 and 7, $\angle A\ O\ I$ is greater than $\angle A\ O\ E$, that is, the current i reaches its maximum, and thereby also any other point of the wave, at a later time, $\angle A\ O\ I$, then the voltage e reaches its maximum (and thereby also any other corresponding point of the wave) at $\angle A\ O\ E$. That is, current i lags behind voltage e in Figs. 6 and 7.

When, some twenty years ago, I desired to represent alternating waves graphically, I thus used this method as the customary and thereby obvious method of dealing with periodic functions in analytic geometry, rather than attempting to devise a new and different method.

Such a different method has however been devised, in the crank diagram, and is used to a considerable extent. It is the method preferred by a number of engineers, but which always appeared to me as rather forced in its derivation, and thus more difficult for the student to get a really good conception of it, as it has no relation to the representation of alternating waves in rectangular co-ordinates (Figs. 1 and 2), which after all is the most obvious and intelligible, and therefore most generally understood, though less suitable for theoretical investigation.

In the representation by the crank diagram, we discard the usual representation in rectangular co-ordinates, as for instance given by the oscillograph, altogether, and proceed to devise a new method: Let, in Fig. 8, a line $\overline{OI}$ be drawn, which by its length represents the maximum value of a sine wave of current,

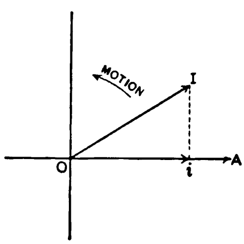


FIG. 8

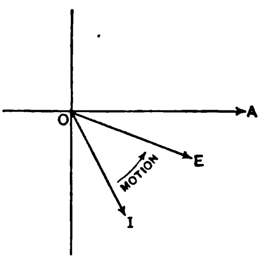


FIG. 9

and assume, that this line OI revolves uniformly, like the crank of a reciprocating steam engine, making one revolution per *cycle*. Then the projection of $\overline{OI}$ on the horizontal represent the instantaneous values of the current. At the moment of time, when the revolving vector $\overline{OI}$ passes the horizontal $\overline{OA}$, the wave reaches its maximum; at the moment, when it passes the vertical, the wave reaches its zero value. If, in Fig. 9, $\overline{OI}$ and $\overline{OE}$ represent respectively a current and a voltage in the crank diagram, in the relative position shown in Fig. 9, $\overline{OI}$ lags behind $\overline{OE}$, since during its rotation it passes the horizontal OA later, than $\overline{OE}$ passes it. As seen, the crank diagram, Fig. 9, is the reverse, or the image of the polar diagram Fig. 6, and to the casual inspector, familiar with one of the diagrammatic representations, the other diagram thus looks as if it used a rotation in opposite direction, that is, clockwise. This obviously is not the case, but both types of diagrams use counter-clockwise as positive direction.

One of the main objections to the crank diagram is, that it is suitable only for sine waves, and with the increasing im-

portance of wave shape distortion, and the increasing necessity of studying distorted waves, resulting from the rapid extension of the. use of the oscillograph, this appeared to me as a very serious objection. To assume, when dealing with distorted waves, that the vector of the crank diagram revolves with a varying speed, or that during its revolution it shrinks and expands in accordance with the deviation of the wave from sine shape, leads to such complication as to be impracticable. This limitation to sine waves appears to me as one of the main reasons, why a standardization of the crank diagram could not fulfil the purpose of securing uniformity of notation, by eliminating the polar diagram, since the latter would still have to be used when dealing with distorted waves, as for instance when working up oscillograph records, etc.

As regards to the terms "direct representation", and "inverse representation", used for distinguishing the two methods of representation, these terms obviously are relative only, and either representation would appear as inverse representation to the engineer familiar with the other representation. To me the polar diagram, which uses the time as co-ordinate, in representing the periodic function of time, always appeared as the more direction representation, and the crank diagram, which introduces mechanical rotation as intermediary, appeared as rather an indirect representation of a function of time, and I am somewhat of the opinion that the crank diagram owes its existence to the notion of mechanical analogy with the motion of the reciprocating steam engine, but it does not appear to me desirable to tie our standard electrical notation to conceptions of steam engine design, but rather to use the established conventions of mathematics, that is, the standard system of polar co-ordinates.

The second topic discussed in Dr. Kennelly's paper is a very interesting and ingenious method of representing power in the vector diagram. I am afraid however, that this method has the same disadvantage as the two methods of representing double frequency quantities, which I once devised, namely, it is rather complicated. This seems to be an inherent difficulty resulting from the attempt to represent a double frequency quantity in a single frequency vector diagram.

Gano Dunn: It would be a great advantage if there were uniformity in vector representation, and as we have the International Electrotechnical Commission, a tribunal that has been organized for the very purpose of acting upon questions of this kind, I move that the International Electrotechnical Commission be asked for a ruling upon the standardization of the direction of vector representation.

This will set to work a large body of authorities whose decisions would be respected by technical authors and those finding would contribute toward removing what is now a serious difficulty.

Those of us who have had the advantage of employing engineers brought up at the feet of Dr. Steinmetz know, when those engineers make a certain diagram, what it means, but there are many other engineers educated under other auspices, who mean just the reverse by diagrams that look like Dr. Steinmetz's and the confusion is growing worse every day.

The difficulty cannot be corrected all at once, but it would disappear in time if all future representations should follow as a standard, one or the other of the present forms.

Wm. W. Crawford: As a pupil of Professor Franklin, to whom Dr. Kennelly has given three places in his tabulation of text-books, I do not feel like allowing this opportunity to pass without saying a word in defense of the counter-clockwise rotating vector diagram. In the elementary text-book of trigonometry which I studied, a positive angle is considered as an angle measured from a certain horizontal reference axis to another line which is rotated in a clockwise direction from the reference axis. The sine of the angle is defined as the projection of a unit length of this line on a vertical axis, and the cosine as the projection on the horizontal axis.

When we come to the study of the alternating current, we are taught that it is represented by a sine curve. To my mind no simpler conception can be obtained than by referring at once to the definition of the sine function and representing our sine wave by the projection on a vertical axis of a rotating vector. Since the trigonometric vector rotates counter-clockwise the alternating current vector should do the same.

John B. Taylor: The use of two confusing methods of representing the same conditions in a vector diagram still continues —a condition which is far from satisfactory. Personally, I studied the direct method, but later, on going to Schenectady, I worked with men who had been under the influence of Dr. Steinmetz, and who naturally were more familiar with his " inverse " method.

It seems fair to say that the two methods discourage many from reading the work of others; cause occasional errors in connections and mistaken predictions and conclusions, besides consuming much time and mental effort which have some sort of a monetary equivalent. For these reasons I want to second the motion made by Mr. Dunn that the matter be brought to the attention of the Board of Directors, for whatever additional formality is necessary, to bring the matter to the attention of the International Electrotechnical Commission, with a view to simplifying this double state of affairs.

Dr. Kennelly does not like the term " wattless power ". Mr. Thomas is with us to-day, and he made quite extensive use of the term last year—some people thought it was a very good term and some did not like it. Possibly some of the members may have looked over the TRANSACTIONS of the Institution of Electrical Engineers and noted the objections to the term

in England. From their published proceedings it appears that objections were raised to the expression " wattless power " in the discussion of a paper, and in defense of the term Dr. Steinmetz was quoted. However, the man who objected to it, said that he did not see that any one other than " a genius unfettered by the ordinary limitations of language " had title to use it.

L. T. Robinson: I also rise in support of the motion. I believe it is the right thing to have this matter referred to some body that will try to decide it in a satisfactory way. Although I have some quite definite views, which are in accordance with Dr. Steinmetz's views in the matter, I think there is no need to put them forth at this time. After hearing the views of two such prominent exponents of the two different ways; at the same time we should have it one way or the other, and have it settled, and I wish to support Mr. Dunn's motion.

C. P. Steinmetz: I also would like to support the motion to refer the matter to the International Commission, because thereby we will have an opportunity to discuss the matter fully. It needs full discussion, before all misconceptions are cleared up. I rotate counter-clockwise, but the quantity which revolves in my diagram is the independent variable, the time, and the vector represents the complete curve of instantaneous values in polar co-ordinates of time. Thus the vector of the time diagram does not represent an instantaneous position, a momentary condition of the periodic wave, but represents the wave as a whole, and the position of the vector is the time of the maximum value of the wave, or of the equivalent sine wave. Thus, on one point we all agree, that counter-clockwise is the positive direction, but the question in dispute is whether in representing alternating waves, we shall consider the alternating wave as represented by the mechanical rotation of a revolving vector, or represented by the stationary vector, of polar co-ordinates of time.

L. T. Robinson: I would suggest that when this matter is submitted to the International Electrotechnical Commission, that Dr. Steinmetz and Dr. Kennelly be asked to submit in behalf of this Institute a brief memorandum covering the facts as they understand them, to aid the Commission in coming to a rapid decision.

Gano Dunn: It was my intention that the question should reach the International Electrotechnical Commission through the American Committee, which would transmit the request of the Convention. Action by the American Committee in bringing the matter to the attention of the Commission would have greater weight if there were the request of this Convention behind it.

It was not intended in referring the question to the Commission that this reference should carry with it any intimation as to which of the two directions of vector representation the American Institute of Electrical Engineers, preferred. My motion was

merely to get our difficulty before the Commission for such suggestions or ruling as they might care to make, and I intended that the channel through which it should be presented to the Commission should be the Commission's American Committee. Our Committee might feel unauthorized to present the question unless there was some desire on the part of the Convention, to have it presented.

It appeared at first that a large majority of those present favored direct rotation but this majority might not have been willing to submit the question to the arbitration of the International Electrotechnical Commission, having in mind that submission involved some responsibility for acting according to what the Commission might find.

As a member of the American Committee I wish to place it in the position of feeling authorized to ask for a ruling from the Commission.

The Chairman: You have heard the motion, which is seconded. All in favor signify by saying Aye; contrary, No. (The motion was carried.)

F. Creedy In connection with Dr. Kennelly's very interesting paper on "Vector Power" a short account of a rather different manner of representing it, which occurred to the writer some time ago, may be of some interest. This makes use of the system of point-analysis due to Mobius and Grassmann, which although very well known to mathematicians, has not hitherto received any engineering applications as far as I am aware.

According to this system the power flowing through a given circuit is represented, not by a vector, but by a point, in a manner slightly akin to the Steinmetz "topographic" representation. The rule for the addition of points is, however, entirely different from that in Dr. Steinmetz's system. The point, moreover, in this system is not a mere mark of position but has a number associated with it which is called its "weight." If the "weight" is zero the point is absent. A point may have a negative "weight." This "weight" is used to represent the effective power while the position of the point with respect to the origin represents the reactive power. We establish the following definitions by convention.

Let S_1 S_2 be any two points of unit weight and $\boldsymbol{M}_1$ $\boldsymbol{M}_2$ be the weights which we attribute to them. Then:

Def. 1 $$M_1 S_1 + M_2 S_2 = (M_1 + M_2)\,\bar{S} \tag{1}$$

where $\bar{S}$ is a point having the position of the mass-center of the points S_1 and S_2 when we attribute to them the weights $\boldsymbol{M}_1$ and M_2. (See Fig. 1). This may be extended to any number of points.

This is the law of point addition. The sum of two points is always in the line joining them and has a weight equal to the sum of their weights.

Def. 2. *The difference of two points of equal weight is the vector joining the points.*

A vector of course has no definite position but may be moved anywhere in the plane.

Def. 3. The effect of adding a vector to a point, say $S+\rho$ is to transport the point from one end of the vector to the other in the direction of the arrowhead on the vector. This follows at once from Def. 2. It is put here merely for convenience. For if

$$S' - S = \rho$$

obviously $$S' = S + \rho$$ See Fig. 2

This may be applied to the representation of alternating current power as follows:

Dr. Kennelly's equation (14) is

$$p_t = P\{\cos\theta + \cos(2\,\omega\,t \pm \theta)\} \tag{2}$$

This may be written

$$p_t = P\cos\theta\left\{1 + \frac{\cos(2\,\omega\,t \pm \theta)}{\cos\theta}\right\} \tag{3}$$

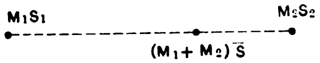


FIG. 1

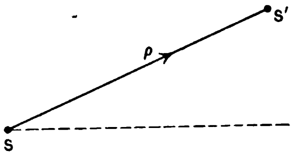


FIG. 2

Case I. All quantities of power which contain no varying component are represented by one point, the origin, associated with a weight corresponding to the amount of power considered.

Case II. Every purely reactive power containing no steady or effective component is represented by a vector exactly as in the ordinary clock-diagram. It shows the position at time *o* of a rotating vector whose projection on an arbitrary axis is $P\cos(2\,\omega\,t \pm \theta)$. The length of a vector representing $\cos(2\,\omega\,t \pm \theta)$ is, of course, unity.

Case III. A quantity of power containing both an effective and a reactive part is represented by adding the vector of case II to the point of case I (the origin). Before we can carry this out properly we must express the power as the product of the effective power, which is the weight of the point, into a unit point. This is done in equation (3) where the expression

$$S = 1 + \frac{\cos(2\omega\,t \pm \theta)}{\cos\theta}$$

represents a unit point at a distance $\frac{1}{\cos\theta}$ from the origin measured along a line making an angle $\pm\theta$ with the axis of reference. See Fig. 3.

Hence we interpret the entire expression (3) as a point at a distance $\frac{1}{\cos\theta}$ from the origin measured in the proper direction, and having a weight $P\cos\theta$. It may be noticed that, as $\cos\theta$ diminishes, the point decreases in weight and at the same time gets further and further from the origin. When $\cos\theta$ vanishes it becomes a point of zero weight at an infinite distance. Now *definition I* gives us the same result when applied to the difference of two points of equal weights, and *definition II* was introduced to remove this ambiguity. *Definition II* enables us to state that:

"A vector is symbolically identical with a point of zero weight at an infinite distance." So that the vanishing of $\cos\theta$ does not introduce any inconsistency but simply reduces case III to case II. In fact, as θ varies the point S moves along

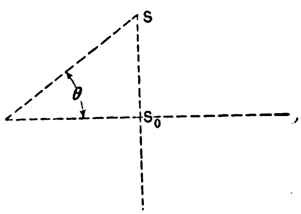


FIG. 3

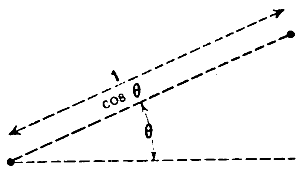


FIG. 4

the straight line $S\overline{S_0}$ perpendicular to the axis of reference. See Fig. 4.

Suppose we have a number of powers

$$p_1 = \rho_1\cos\theta_1\left\{1+\frac{\cos(2\,\omega\,t+\theta_1)}{\cos\theta_1}\right\}$$

$$p_2 = \rho_2\cos\theta_2\left\{1+\frac{\cos(2\,\omega\,t+\theta_2)}{\cos\theta_2}\right\}$$

$$p_3 = \rho_3\cos\theta_3\left\{1+\frac{\cos 2\,\omega\,t+\theta_3}{\cos\theta_3}\right\}$$

etc.

these may be written, by the principles enunciated above

$$m_1\,(1+\alpha_1),\ m_2\,(1+\alpha_2)\ m_3\,(1+\alpha_3),\text{ etc.}$$

where α_1 α_2 α_3 are the vectors representing $\frac{\cos (2\omega t+\theta)}{\cos\theta}$ etc.

The origin at unit weight, is here typified by the scalar or numeric, 1, and may be called the "scalar point"
Adding these together, we get

$$m_1 (1+\alpha_1)+m_2 (1+\alpha_2)+m_3 (1+\alpha_3)$$

$$= (m_1+m_2+m_3)+m_1 \alpha_1+m_2 \alpha_2+m_3 \alpha_3$$

$$= (m_1+m_2+m_3) \left(1 + \frac{m_1 \alpha_1+m_2 \alpha_2+m_3 \alpha_3}{m_1+m_2+m_3}\right) \tag{4}$$

$$= M (1+\alpha)$$

The expression

$$\alpha = \frac{m_1 \alpha_1+m_2 \alpha_2+m_3 \alpha_3}{m_1+m_2+m_3}$$

is the well known expression given in the first chapter of every textbook of vector analysis for the vector to the mass center of three points, of masses m_1, m_2, m_3, situated at the extremities of the vectors α_1, α_2, α_3. Or, alternatively, let us add the expressions p_1, p_2, p_3, together direct. We get

$$p_1+p_2+p_3 =$$

$$\rho_1 \cos\theta_1+\rho_2 \cos\theta_2+\rho_3 \cos\theta_3$$

$$+\rho_1 \cos\theta_1 \frac{\cos (2\omega t+\theta_1)}{\cos\theta_1} +\rho_2 \cos\theta_2 \frac{\cos (2\omega t+\theta_2)}{\cos\theta_2}$$

$$+\rho_3 \cos\theta_3 \frac{\cos 2\omega t+\theta_3}{\cos\theta_3}$$

$$= \rho_1 \cos\theta_1+\rho_2 \cos\theta_2+\rho_3 \cos\theta_3 \left\{ 1+ \frac{\rho_1\cos\theta_1\frac{\cos(2\omega t+\theta_1)}{\cos\theta_1}+\rho_2\cos\theta_2\frac{\cos 2\omega t+\theta_2}{\cos\theta_2}+\rho_3\cos\theta_3\frac{\cos 2\omega t+\theta_3}{\cos\theta_3}}{\rho_1\cos\theta_1+\rho_2\cos\theta_2+\rho_3\cos\theta_3} \right\}$$

which is of exactly the same form as the above expression (4) in vectors so that the appropriateness of the point-analysis is quite clear.

These remarks are already too long, so that I must refrain from giving any applications, of which few have yet been made.

However, for the benefit of anyone who cares to pursue the subject further, I give a few references.

Although the point-analysis is actually due to Möbius and Grassmann, the immediate inspiration of this application, and the notation, is due to Professor C. J. Joly's memoir "The Interpretation of a Quaternion as a Point Symbol" Trans. Royal Irish Academy, Vol. **32**, Sec. A, Part 1, further amplified by him in his "Manual of Quaternions" and "Quaternions and Projective Geometry" Phil. Trans. Royal Soc.

The best books on Grassmann's Algebra in the English language are

"The Directional Calculus" E. W. Hyde, (Ginn & Co.), Boston; and "Universal Algebra" A. N. Whitehead, Camb. Univ. Press.

A very rudimentary acquaintance with these subjects is enough to enable one to do much useful work. I do not want to give the impression that the method cannot be used until all these ponderous volumes have been thoroughly mastered.

A. E. Kennelly: I think we all agree, as a result of this very interesting discussion, that vector representation can be arrived at in two ways—by Dr. Steinmetz's method and also by the trigonometrical method, and the fact that we can legitimately divide them in these two ways is what causes the trouble. If we can get some expression from the International Electrotechnical Commission, and if we can get an international decision upon that point, I for one, and I am sure that all of us would be very willing to adopt that one method, whichever it may be, and if this action of the Institute will bring that happy result about, I think it will be a great boon to electrical engineers all over the world.

The first official meeting of the Commission is scheduled for next year in Berlin, but an unofficial meeting is scheduled for this year in Brussels, and if this matter can be brought to the attention of the body at the unofficial meeting this year, it is possible that the work of the body on this subject could be completed in a year's time.

In reference to the able remarks of Dr. Steinmetz, we must all admit that whatever convention is internationally adopted on vector diagram directions, it must not conflict with fundamental mathematics. If it were demonstrable that inverse representation in vector diagrams conformed to the established laws of analytical geometry, whereas direct representation contravened those laws, then it would follow that inverse representation should be followed internationally as a matter of necessity. To my mind, however, no such necessity exists. If we plot a polar-coördinate representation of a voltage and a current, as we have a perfect right to do mathematically, and in the manner described by Dr. Steinmetz, we are not forced to make any vector diagram by drawing diameters to the circles, or equivalent circles, on the curve-sheet. The representation of the vector voltage and current, by straight lines taken on the

diameters of their respective circles, seems to be a pure convention, not fundamentally involved in the analytical geometry. This convention of taking the diameters for vectors in a vector diagram, leads indeed to inverse representation, as pointed out in the paper; but another convention might equally well be adopted, which would involve direct representation. For instance, the two polar circles of voltage and current might be brought into line with each other, diametrically, and two separate suitably dephased radii vectors might rotate together, so as to intersect these circles, and represent by their intercepts at any instant, the respective magnitudes of the cyclic quantities. The two radii vectors would then, by convention, represent the voltage and current of the vector diagram, with direct representation. Or convention 4 of the paper might be used, with direct representation, from polar coördinates.

Again, exception may be taken to Dr. Steinmetz's view that the crank diagram " has no relation to the representation of alternating waves in rectangular coördinates ". In a number of text-books, the rectangular-coördinate diagram of a wave is derived from, and made dependent upon, the crank diagram. It seems evident, on deliberation, that a vector diagram is essentially a conventional diagram. That is, it is based upon fundamental mathematics through the medium of some particular convention or conventions. We may safely standardize our conventions without discriminating against the fundamental mathematical operation or laws. Surely it cannot be maintained that because we represent our vectors on paper as having a certain order of angular sequence, that therefore we cannot plot our cyclic magnitudes in any particular coördinate system.

Apart from the preference that springs from mental habits, it is submitted in the paper that either of the conventions here called " direct representation " and " inverse representation " is as good as the other. Each can claim to be descended from pure mathematics, the direct representation from trigonometry, and the inverse from polar coördinates. The only reason claimed in the paper for calling the former *direct* representation, is that when laid off in this manner, the vectors follow in the order of time. The leading vector quantity is ahead of the lagging quantity in the direction of positive rotation.

It is surely of the utmost importance to adopt a standard universal convention of vector sequence and representation. The advantage to each engineer of having one and only one representation in use in alternating-current literature, far outweighs the trouble of having to change one's own familiar method. I would much rather change my own habit in this matter than continue to encounter the perennial medley of different methods of representation in different papers, and I believe that most of our confreres all over the world are of the same opinion.

The important thing is a unanimous agreement. It is of relatively lesser importance which way the decision is taken.

DISCUSSION ON "DISRUPTIVE STRENGTH WITH TRANSIENT VOLTAGES", "THE ELECTRIC STRENGTH OF AIR" AND "DIELECTRIC STRENGTH OF OIL". JEFFERSON, N. H., JUNE 29, 1910. (SEE PROCEEDINGS FOR MAY AND JULY, 1910.)

(*Subject to final revision for the Transactions.*)

D. B. Rushmore: Mr. Whitehead in his paper says something which is perhaps more true than many people realize: "As a result of the increase in values of transmission voltage, however, and of improvements in high voltage apparatus and line insulators, the electric strength of air has become a limiting factor in the long distance transmission of power." It is only of a very recent period that this has been true. It is, however, of great interest and import. In the somewhat old problem of transmitting power, one obstacle after another has been overcome until at present we are confronted with the effect of the insulating properties of air, and what action will be taken with regard to overcoming the obstacles presented by it is a question of much importance at the present time. Until very recently, line insulators were the limiting feature, and at 60,000 volts the standard form of insulator was operating near its limitations. With the new suspension insulators, however, the line can be insulated far beyond the point at which the dielectric strength of air will stand. The question of altitude in transmission lines is also becoming important, because of the lower dielectric strength of air at the higher altitudes. The physical phenomena which take place when corona has formed are extremely interesting, and a considerable number of points arise in connection with it. For instance, it is not quite clear without fuller understanding, why corona should cease to be formed by the lower voltages than that at which it begins.

The phenomena described in the paper are those which are of immediate interest to many members of the Institute. To take an example, a line which was to operate at 60,000 volts had the design of the insulators carefully worked out so that they would always flash over before puncturing. A number of times, however, lightning punctured these insulators and the dielectric time-lag of air was used to explain the occurrence. Also many operating engineers are familiar with the slight blackening of the bright copper wires in their stations, due to the effect of corona formation.

The problem of how best to perform experiments of this kind is a difficult one. We all like to see the conditions surrounding such investigations as nearly as possible like those under which the application of the results will be made, such as the interesting work carried on by Mr. Mershon some years ago on outside commercial lines. It is, however, extremely difficult to obtain exact data in this way, and it would seem that the basis for our engineering recommendations must to a large extent be the result of experiments carried on in the Laboratory.

The relation of power or energy to breakdown or ionization is not clear, and the effect of frequency on such dielectric failure still remains a subject for discussion. The point most deserving of attention is that the future progress of the art depends very largely on the results of the study of the properties of dielectrics. The characteristics of this class of material bring about the limiting features in high voltage power transmission.

V. Karapetoff: Those familiar with the history of the theory of elasticity and of the mechanical strength of materials will find it quite similar to the history of practical electro-statics. During the early stages of the development of civil engineering the engineers who needed to know the strength of columns, bridges, etc., tested them in their actual complicated shapes. The result, therefore, did not characterize the materials, but only certain objects of definite dimensions made out of these materials. Knowing the strength of a column or of a beam of a certain size, it was not possible to predict the strength of a column or of a beam of a different cross-section and of a different length. Then, gradually, a theory of resistance of materials was developed and formulae established into which the elastic coefficient of a material, the dimensions of an object made out of this material, and the given forces entered as independent factors. The next stage in the theory was to combine various stresses and to combine the resultant strains. In most structures and parts of machines there is usually more than one set of stresses (for instance a normal stress and a shear), and unfortunately stresses are combined according to a different law than the resulting strains. Finally the fact became clear that it is the resulting *strain* and not the stress that limits the safe load of a piece of material—I am speaking of mechanical strength now—no matter by what combination of stresses the strain is produced. As the last step, the theory was extended to include the action of *dynamic* loads or what we call in electrical engineering *transient* loads. In bridges, in reciprocating engines, and in the many other cases loads are not steady, they are intermittent; kinetic energy and inertia enter therefore as disturbing factors.

A similar development took place in applied electrostatics. Our predecessors started with a theory of charges acting at a distance. Naturally, with such a wrong assumption, not much progress was made, because the phenomena take place in the dielectric and not on metallic surfaces.

After Faraday and Maxwell had cleared the way for a correct interpretation of electrostatic phenomena, and after it had become necessary for engineers to take into account the dielectric strength of materials, a new impetus was given to electrostatic experiments. But as in the case of early experiments on columns, beams, etc., " practical " electrical engineers still use electrodes of all kinds of fancy shapes, from which the dielectric strength of dielectrics proper cannot be conveniently calculated. Know-

ing, for instance, the striking distance between two pointed electrodes, it is impossible to calculate the striking distance between electrodes of a different shape, or to determine the critical voltage with the same electrodes at a different distance. The question is, however, being gradually put on a more rational basis; it is at present clearly understood by physicists and by many engineers that the striking distance per centimeter of air-gap between needle points really does not mean much, as regards the dielectric strength of air. Experiments must be preferably made on large (practically infinite) parallel plates, in which case the stress in the dielectric is the same at all points. Or, else, electrodes must be used of such a shape that the true strains (critical dielectric flux density) can be calculated from the striking distance. Concentric cylinders are convenient for the purpose.

I wish to refer to the sketches Figs. 1, 2 and 3 of Mr. Tobey's paper, which illustrate my point. The sketches show the difference between a uniform dielectric field in the case of parallel plates, and non-uniform fields in the case of sharp points on spheres.

In a non-uniform electrostatic field it is necessary to consider the actual stresses from point to point, because the air is not broken down simultaneously at all points. It is possible to break down certain portions of the air nearest to the electrodes, to ionize it, to make it a conductor, without producing a jump-spark. The air so ionized becomes a part of the electrode, so that the break-down finally occurs between new shapes of electrodes. This leads to the consideration of the quantity usually called the electrostatic capacity between two electrodes, but which ought to be more properly called the *permittance of the dielectric*. By using proper values of permittance and "permittivity" of the dielectric, calculations of the dielectric strength of insulation are put on the same scientific bases as calculations of conductors of non-cylindrical shapes.

At present we are not yet advanced far enough to be able to calculate the distribution of electrostatic stresses in all cases, but in the simplest cases, for instance, such as is presented by Dr. Whitehead, or in the case of two spheres, it is possible to calculate the actual stresses and their distribution. It is not the average strength of the air, considered as a mass, that interests the engineer, but the *weakest point* at which the air breaks down. The safety of insulation must be considered with regard to this weakest point, the same as the civil engineer figures out the factor of safety of the weakest part in his bridge. And fortunately the electrical problem is simpler than the corresponding problem in the theory of elasticity, because there we have two kinds of stresses, normal stress and shear, while in dielectrics there is but one kind of stress. I do not know what kind it is; perhaps it is some kind of shear between positive and negative electricity; at any rate we have to consider only one kind of stress.

Now we come to the last stage, the same as civil engineers had to face, namely, the effect of dynamic loads, of transient voltages. The paper by Mr. Hayden and Dr. Steinmetz represents the results of a pioneer investigation in this field. Let us consider their experiments in the light of a mechanical analogy, that of an elastic rod or a column suddenly subjected to a normal stress by a released weight. Is it correct to say that the weight is instantly balanced to its full extent by elastic forces in the rod? To me such an assumption contradicts the laws of mechanics of elastic bodies.

In order to produce an elastic reaction a strain or a deformation must first occur in the rod. The rod can resist only (1) as the result of such a strain (elasticity), or (2) by opposing an acceleration of its parts (inertia). In the case under consideration there is no initial strain in the rod, and in order to produce it parts of the rod must be accelerated layer by layer. At the very first instant the load is balanced by a very high acceleration of a very small part of the mass of the rod adjacent to it; then the next layers are accelerated so that we get the effect of a travelling compression wave. Only after a certain displacement has taken place the load is balanced in part or in full by the elastic forces. Hence this paradox that with a very short application of the weight, that corresponds to our transient voltage, the column or the rod can seemingly support without being destroyed a heavier load than with a load applied gradually. Is it not more logical to suppose that the molecular strain, the *actual strain* at which the material breaks down, is the same in both cases? Only in the case of a transient application a part of the load is balanced by the acceleration of the mass and has no time to produce elastic stresses, before the load is removed.

It seems to me that the results obtained by Mr. Hayden and Dr. Steinmetz must be interpreted in the same light. I cannot conceive how a voltage of say 100 kilovolts can be applied suddenly to a neutral dielectric, that is to say to a dielectric which is not strained. The action must be equal to the reaction, and a dielectric which is not strained can produce no electrostatic reaction. It can react only electromagnetically, by means of displacement currents in it, or in the other parts of the circuit. I am willing to grant that the voltage calculated by the authors was actually induced in the high-tension windings of the transformer, but it does not follow from this that at the very instant of the closure of the primary switch this full voltage acted across the air-gap, producing *static* stresses in the dielectric. The electromagnetic inertia effects are predominant at the first instant.

The slope of the voltage wave is very steep at the first instant; therefore, even a very small magnetic leakage between the two windings of the transformer, a leakage negligible with ordinary frequencies, must have produced an enormous counter-electromotive force. I am inclined to think that at the first instant the voltage between the electrodes was practically equal to

zero. The unstrained dielectric acted as a short-circuit, and the applied voltage was balanced by the reactance counter e.m.f. We must remember that the rush of current at the first instant is tremendous, in order to produce the required displacement in the dielectric. There could have been also a considerable magnetic field in the dielectric proper. We have in reality a much more complicated phenomenon, *electromagnetic* as well as *electrostatic*, than it appears on the surface. It is hardly scientific to say that we simply have 100 kilovolts momentarily applied to air or oil, and that momentarily these dielectrics can support more than with a steady application of the voltage.

We must be particularly careful now, when we just begin to understand the full meaning of these phenomena, not to describe them in a "short-hand" way, but to specify carefully the actual physical relations. Without this precaution, busy practitioners are only too prone to misunderstand the results, and to apply them in cases for which they were not intended at all.

Percy H. Thomas: Professor Whitehead's paper suggests many questions that I presume he is not in position to answer as yet, but there are a few points which I think would clear up some matters.

Professor Whitehead has apparently made a very desirable advance in having devised a method for the study of corona and allied phenomena in which he can eliminate all variables which he does not control. His tests, being laboratory tests, and made under somewhat limited conditions, do not tell us everything about corona, but apparently he has succeeded in controlling all the variables actually present in his tests, so that he can absolutely reproduce his results on different days and under quite different circumstances. With such a result realized, it is possible to add another known variable, and get its effect, and so on step by step.

I ask Dr. Whitehead if he will tell us something concerning the electrical conditions at the ends of his tube.

I would ask Dr. Whitehead if it is possible that the peculiar action of small wires in giving the apparently high dielectric strength for air could be due to the fact that near the surface of the small wire the strain is changing rapidly. That is, the volume of air that is subjected to the maximum stress is very much more limited than where the wire is larger; the potential gradient being much sharper in the case of the small rods.

I would ask whether the air which passes through the tube coming from the wire at the time of the formation of corona is ionized in the sense that there are positive and negative charges therein equally balanced, or whether it comes away with a predominant positive or with a predominant negative charge, and if so, which? Also whether he has tried any other gases than air.

Another point, in the visual observation of the corona through oscillographs, has he observed both positive and negative waves,

direction being taken with reference to the test wire—that is, were observations made with the positive potential on the inner wire or the negative potential on the inner wire, or with both? If so did any difference appear?

One other question—I would ask how the actual arc, that is, the complete break down, follows after the ionization first begins, that is how wide a range of voltage, for example, exists between the point where you can first observe a rapid dropping of the electroscope, and formation of the actual arc.

A. E. Kennelly In regard to one particular point in these very interesting papers, Dr. Whitehead emphasizes the fact the electric intensity at which disruption appears is greater for small wires than for large wires. A suggestion for the reason of this remarkable phenomenon may be offered tentatively. We know, referring to the properties of the magnetic field for a moment, that a small magnetically polarized iron particle, or iron filing, is not acted upon by any magnetic force of translation—any bodily moving force—when subjected to a uniform magnetic field, or a magnetic flux distribution acting in parallel straight lines. There are forces of rotation, couples, or torques, but no forces of translation. When, however, the magnetic field is not uniform but divergent, the iron filings are subjected to translatory forces as well as couples, and are pulled bodily towards the denser parts of the field. This effect may roughly be described by saying that the magnetic pull, in the denser part of the field, on the attracted pole, is less than the opposing push, in the weaker part, of the field on the repelled pole. In fact, we know that the pull of a divergent field $\mathcal{H}$ upon a spherical iron particle or spherical iron filing depends upon the product $\mathcal{H} \cdot \frac{d\,\mathcal{H}}{d\,s}$, where $\frac{d\,\mathcal{H}}{d\,s}$ is the greatest space rate of change of the field.

Now returning to the electric field, if we may assume that a molecule of gas subjected to an electric field is polarized thereby, then the molecule will be subjected to a couple or aligning force; but if the electric field is uniform, there will be no pull, or force of translation, on the molecule. If, however, the field is convergent, a force of translation will exist as well as the couple, and the molecule will be pulled towards the denser part of the field. In the case of an electrified round wire, the field will be radially divergent from its surface, and the divergence will be numerically greater, the smaller the wire's diameter. We should, therefore, expect air-molecules to be drawn in towards the surface of the wire, and to crowd together near that surface, just as though the atmospheric pressure were locally increased in this vicinity. If such a local increase of air-density occurred around and near the surface of a wire, the electric intensity required to produce disruption should be increased, as it increases with the atmospheric pressure, and the increase should

be greater the smaller the wire. I tried the experiment recently, with Dr. G. W. Pierce, since reading Dr. Whitehead's paper, of electrifying a two-millimeter wire running down the axis of a glass tube and observing whether the pressure of the air, within the tube as a whole, became thereby altered with respect to the pressure of the air outside the tube. We were unable to detect any such effect. Consequently, although the effect above suggested might occur, and might yet be masked in this experiment by opposing actions, yet it must be admitted that thus far, the suggestion is not supported experimentally.

W. H. Pratt: There is one suggestion which comes to me in connection with the second paper, which has read. The results quoted with moist air are apparently in disagreement with certain other measurements which have been made. May it not be that moist air, as we find it in the open, at times contains electric nucleii due to the partial re-evaporation of condensations that have occurred around these electric nucleii, and hence the moist air, at such times, is really somewhat conducting, whereas in the experiments that were outlined, the moisture was added to the air in such a way that it certainly would not be expected to be conducting.

E. E. F. Creighton: Two of the big problems in the transmission and distribution of electrical energy are the lightning protection of the transmission circuit and the suppression of troubles from internal surges of electrical energy. The dielectric spark lag and the spark energy enter into both problems and most vitally in the latter. Speaking of internal surges only, it has been noted here and there all over the country that transformers and generators would fail at some internal part of the winding. On any particular system these failures are rather infrequent, but the aggregate is considerable. Some time ago this problem of internal surges was confused by the presence of end turn effects. Modern designers have eliminated the end turn failures by heavily reinforced insulation. This leaves the problem of caring for internal surges distinct and prominent. The conditions of cost are not such that a designer may place everywhere in the windings, as he does on the end turning, an insulation that will stand a test pressure of 6,000 to 20,000 volts when the dynamic voltage normally present is only ten to twenty volts. The amount of energy in these internal surges is usually small. The excellence of a design taking these factors into consideration would never be casually apparent, yet they would be vital. With these practical features in view, the theoretical and experimental studies made by the authors assume a great importance. Careful measurements are the life of further progress. A simple method of test is given which can be extended easily to further studies.

The speaker has had occasion to study a particular feature of the dielectric spark lag of protective apparatus, with the object in view of getting rid of it. We were surprised to find lags extending to several seconds. To the speaker's knowledge

this long lag has never been observed before. These data have a strong bearing on the subject of the paper. Among several other things, the dielectric spark lag depends on the excess voltage above the voltage which would cause a spark to pass if applied for a long time, theoretically for an infinite time. For brevity, call this, excess voltage the super-spark potential.

As would naturally be expected, the relation between the super-spark potential and the time, is hyperbolic. For very great superspark potentials the time interval before the spark passes becomes only a few milliseconds, or may even go down into the microseconds.

In the curve herewith reproduced the measurements were taken by the simple method of the oscillograph. Direct current potential was applied to a gap and the time interval measured between the application of the potential and the beginning of the current in the spark. The points of slight super-spark potential deviate very little from hyperbolic curve—in this particular

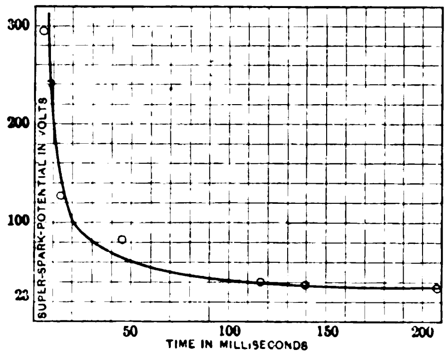


Fig. 1.—Super-spark potential curve. The points are taken by measurement and the curve is the hyperbola $x\ (y-23) = 1780$

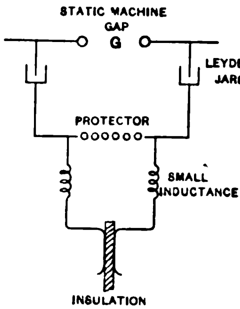


Fig. 2

case $x\ (y-23) = 1780$. (See Fig. 1). But the points at considerable super-spark potential are somewhat variable, showing an erratic behavior not understood at present. At only 35-volt super-spark potential, the lag is 200 milli-seconds. At 250-volt super-spark potential, it is 20 milliseconds. At 300-volt super-spark potential it is 6 milliseconds.

The asymtote to the curve is 23 volts above the spark potential at an infinite time of application. This may have been due to difference in conditions of tests as this value was taken some time previous to the other readings.

The dielectric-spark-lag was demonstrated by another test using alternating potential. The spark-potential for continuous application was less than the peak value of the alternating potential, yet under these conditions it was not possible to spark across the gap. Successive alternations apparently deionized the gap. At any rate the time of application of super-

spark-potential was not sufficient to cause a spark and the successive impulses were not cumulative.

The obnoxious effect of the spark lag on the operation of lightning arresters was noticed first, years ago, in taking equivalent needle-gaps and other direct measurements of the value of lightning arresters.

The gap at *G* of a static machine requires a certain pressure to spark. (Fig. 2). This determines the value of pressure that will appear at the protector. At the terminals of the protector is attached the insulation to be protected. Between the protector or lightning arrester and the insulation a small amount of inductance is placed to imitate circuit conditions. When the pressure at *G* was as high as 100,000 volts, the insulation was not injured as the spark took place quickly at the protector. When, however, the electric pressure at the gap (*G*) was relatively small, in one case about 3,000 volts, the insulation was punctured. The greater time lag of the protector allowed the charge to pass beyond into the insulation and although the spark sometimes took place in the protector, it occurred too late to give protection.

In regard to Dr. Whitehead's paper, I wish to say that in the study of the dielectric spark-gap, we came across the same thing that he has studied in what he has named dirty wires, or the oxidation of the wire. We had ionization taking place on wires which allowed a spark to pass at less than fifty per cent of the normal spark potential, and I felt that it could not be explained by any roughness of the surface. It seemed evident from the tests we made, that the ionization was due to the oxide on the surface, in some inexplicable manner. In other words, the oxide apparently causes a considerable degree of auto-ionization. After we removed the oxide it disappeared, although the surface was equally rough. The tests were made in hydrogen vapor, and consequently the oxide on the copper was reduced by the passage of an arc over the surface. These results are suggestions although the phenomenon may be different from the effect of duty copper wires in air.

J. C. Lincoln: There is one question I would ask Dr. Whitehead. In the diagram of his apparatus, he shows a wire in the medium which is controllable, and I take it from the diagram that there is passed through the medium an alternating voltage, and therefore that the ionization, such as there would be, would tend to produce positive and negative ions in the tube, and in that way the ions are passed across the indicating instrument and some kind of an indication is given. Apparently either the negative or the positive ions are in preponderance, and I would like to know which did preponderate.

Charles F. Scott: I want to say a word in appreciation of the three papers which have been presented, and the work they represent, and the valuable part which these papers will play in the progress of the art.

In going into a new field like this high voltage field, there is

good deal of pioneer work to be done of two kinds—work in the laboratory and work in the field, theoretical work and practical work. Very often these alternate. First we take one kind of step and then the other. Dr. Whitehead enumerated several papers which have been presented to the Institute, which are preliminary to his, and form a series. In running over these papers, I note the first one is on the dielectric strength of air by Dr. Steinmetz, a laboratory paper; next is the Telluride test by Mr. Mershon, which was a field test; next is the paper by Professor Ryan, a laboratory test; next follows a Mershon paper, giving field tests, and now the Whitehead paper, a laboratory paper follows. The next thing on the regular schedule would be to have another paper from Mershon.

Harris J. Ryan: Dr. Whitehead's paper is a most valuable contribution to the subject.

The writer agrees with the author that " secondary ionization is the cause of initial breakdown and formation of corona." For out-door conditions he prefers the terms " native " ionization to " antecedent " ionization as used in the paper. He differs from the author in the conclusion that native ionization enlarges the effective terminal until the stress (intensity) at its surface falls to the ionizing value. *Native ionization strengthens the stress near the terminal and diminishes the distance to the ionizing zone. This distance is required to accelerate the ion to the ionizing speed.* At a stress of 76 kilovolt-in., or 30 kilovolt-cm., ions travel nearly one inch in 0.0002 second. The region about the electrode enclosed by the zone in which the corona starts contains mostly native ions of opposite polarity. Such ions will strengthen the stress and lessen the accelerating distance to the corona forming zone.

Recent studies of the normal in-door air show that the value of J. J. Thomson and the one in which the author of this paper expressed confidence, a year ago, is correct, namely, 76 kilovolt-in. There is much evidence that 40 kilovolt-cm. as given now by the author is too high for normal in-door air.

The rapid outward spread of the stress from the surface of a small conductor and the greater concentration of native ions combine to make the accelerating distance to the initial corona zone shorter. Since the initial corona zone always forms in the normal air at 75 kilovolt-in., the net result is that the surface stress of the conductor rises as the initial corona striking distance falls.

In regard to the statement " In view of these discrepancies one naturally turns to Mershons' method for measuring the loss as a possible source of error." A careful study of the methods used at Niagara and recent laboratory tests have convinced the writer that Mershon's methods and results are correct. There are no real discrepancies. The surprises are due mainly to the larger native ionization at the Falls. Mershon's Niagara corona zone stresses go below 75 kilovolt-in., because of irregular

distribution of stress about parallel conductors worked with alternating high-tension; this irregularity is produced and enhanced by the larger supply of native ions occurring at Niagara Falls. The vapor-product is an indirect evidence of their quantitative variation.

R. D. Mershon: Referring to the paper by Mr. Hayden and Dr. Steinmetz, I would ask them to make clear how they determined the energy available at the spark gap; how they found out what energy was effective.

C. P. Steinmetz: We did not determine it, do not know it.

R. D. Mershon: Then it seems to me it is pretty hard to arrive at any definite conclusion.

C. P. Steinmetz: The only conclusion is the total energy supplied to the apparatus, hence the energy at the spark gap must be less than that. We give only the energy limit.

R. D. Mershon: The question of energy is related to that of voltage. I do not see how you can have any idea of the voltage finally impressed upon the dielectric.

C. P. Steinmetz: I will answer that in the final discussion.

R. D. Mershon: Referring to Dr. Whitehead's paper, the questions and doubts he raises in regard to the accuracy of my high-voltage measurements at Niagara are all of them questions and doubts which I myself raised at the time the results were obtained, and which I feel were resolved by the careful tests made of the accuracy of measurement. We tested out the method of measurement in every way possible and in consequence of these tests I am well satisfied that the method of measurement is a reliable one, and that the results obtained are substantially correct. I feel confident the accuracy of the measurement is within 5 per cent, and probably much closer than that. Reference to my paper will show the kind of tests made, and the method of making them.

The apparatus used at Niagara was not that used at Telluride. It was of the same kind, but better designed and executed. At Telluride I had a 1,000,000-ohm resistance with which to test out the accuracy of the measuring apparatus. At Niagara no such resistance was available, but in view of the closely checked results obtained at Telluride making use of the resistance, together with the fact that the Niagara apparatus was an improvement on that at Telluride, and in view of the results of such check-readings as could be taken at Niagara, I have no suspicion whatever of the accuracy of the Niagara apparatus and the results obtained with it.

Dr. Whitehead says:

"Since Mershon's observations appear to have been taken in all seasons, it may be stated that a range of temperature of 35 deg. cent. and a pressure of 25 mm. of mercury, and an error of 5 per cent in the critical point as taken from the curves, would give a range of critical voltage as wide as that attributed by him to moisture".

I judge from this that Dr. Whitehead thinks the relation I found between critical point and vapor product may be the re-

sult of a series of errors. If this is the case, it is curious that these errors should have occurred so consistently over a year and a half, during which time measurements were taken almost every day.

I do not see how it is possible that any errors in our observations or in our method of measurement could account for the variation of critical point with vapor product. The effect was entirely too marked to be so accounted for. Before we discovered the relation between loss and vapor product, we would sometimes get consistent results over a period of several days, and then the results of the next day would be all out of line. It even happened at times that of a set of observations all taken on the same day the results would be erratic and entirely inconsistent. But all these readings, when interpreted by means of the vapor product, came together and were consistent; the results of different days came together; discrepancies occurring on the same day were reconciled. So I cannot conceive of the relation referred to as being in any way due to errors in either measurements or apparatus.

In this connection I would call your attention to the facts brought out in one of the other papers here, relative to the very small amount of moisture necessary in oil in order to enormously change its dielectric qualities. In what condition does that moisture exist in the oil? Is it water, or vapor? It certainly must be very finely divided, at any rate, for it is uniformly distributed through the óil. This may have a considerable bearing upon the loss in air due to moisture; a loss entirely aside from the so-called ionization loss.

The only error that I can conceive of as possible, due to the method of measurement, would arise from phase displacement in the measuring apparatus itself. The tests made of the apparatus, as detailed in my paper, seem to me to pretty clearly show that there was no such error, or at any rate it was not great enough to account for the discrepancies, if you may call them such, between my results and those of Professor Ryan and Dr. Whitehead.

I would call your attention to the fact that the results obtained by Dr. Whitehead, and to a considerable extent, the results obtained by Professor Ryan, are not necessarily comparable with my results. I did not investigate the matter of ionization. I investigated the point at which the loss between outdoor transmission line conductors begins to rise rapidly, which point I called the critical point. I do not think this loss is necessarily all ionization loss. It seems to me it may include losses other than those due to ionization. The results of Professor Ryan and Dr. Whitehead were obtained under laboratory conditions. My results were obtained under engineering conditions. I do not believe we are safe in applying the results of laboratory investigation to the engineering problem, unless we can check up these results under engineering conditions.

There are too many other elements which may enter to modify laboratory results as applied in practice.

What I have said applies to the conclusions. Conclusion 5 says, "Water vapor or moisture has no influence on the electric strength of air. Increasing moisture content probably lessens the loss above the critical voltage". That depends on what you mean by the critical point. If you mean the point at which ionization begins, the statement is possibly true, but if you mean the point at which the loss between the wires of a transmission line begins to rapidly ascend, I do not agree with that at all. Similarly with regard to Conclusion 6—"There is no loss through air until the critical voltage accompanied by ionization and corona is reached". I believe there may be a loss below the critical point, as I have just defined it, and that this critical point does not necessarily correspond to the inception of ionization.

Now, as regards Conclusion No. 10: "The corona has high conductivity, and most of the loss takes place beyond it". I do not remember anything in the paper which would appear to justify this conclusion. If there is, I shall be glad if Dr. Whitehead will bring it out more strongly.

Referring to Mr. Tobey's paper, Fig. 7 would be much more interesting if the melting point of the oil were shown, and it is to be hoped that in closing Mr. Tobey will give us the melting point. This curve presents some facts in regard to which I have often wondered. I have been afraid sometimes that if the oil in transformers was allowed to solidify, due to cold, we might get into trouble, but according to this curve we are safer with the oil solidified than with it in its normal condition.

C. P. Steinmetz: First, to answer some questions regarding our paper—the energy values, are, as stated in the paper, not the energy appearing at the spark-gap, but are the total amount of energy supplied to the system through the transformer, and, as stated in the paper, the actual energy supplied to the spark-gap probably is only a small part thereof, so that these values merely mean the upper limit of energy, which is sufficient to break down the gap, and probably much less energy will be enough.

As regards the question whether the voltage was actually at the spark gap or not, we carefully looked into the matter and came to the conclusion that this voltage is there, at least approximately this voltage, as near as it was possible to judge. Mathematically, I gave the reasoning in the appendix, which shows how we calculated the voltage which appears at the secondary terminals and thereby at the spark-gap. We know if there is one thing where experiment and calculation agrees, it is in transient phenomena, provided you consider all the factors involved in the problem.

There are two factors which have not been included in that mathematical calculation. One is the variation of the in-

ductance; the second is the capacity of the secondary circuit. It can easily be seen that the variation of the inductance with the voltage has no effect on the voltage, but merely modifies the shape of the voltage curve of the secondary. There remains then the consideration of the secondary distributed capacity. From the constants of the transformer, its estimated resistance, inductance and capacity, it appears obvious, that the effect of capacity could result only in an oscillation, not in a steady change, that is, that at the beginning of the impulse there might appear and probably does appear an oscillation superimposed on the steady discharge curve, calculated in the appendix. Such oscillation may be either limited to the high voltage circuit, and then be of very short duration or small energy, or it may extend into the primary circuit.

In the paper we gave evidence that such oscillation did not extend into the primary circuit, by changing the resistance of the primary circuit, increasing the non-inductive resistance of the primary supply circuit nearly a hundred-fold, and getting the same result. It is obvious if there is any oscillation taking effect in the primary, that by increasing the resistance of the oscillating circuit nearly one hundred-fold, from about $\frac{1}{3}$ ohm to 26 ohm, the oscillation must be enormously reduced and damped out, and we found the same transient discharge. I believe, however, there was in the high potential secondary circuit an oscillation superimposed on the exponential curve of the calculated voltage ratio, but of extremely short duration, and as the entire effect is a transient, you see that an oscillation of still much shorter duration at the beginning of the effect, could not well be expected to have an appreciable effect. It is, however, desirable, and we hope some time to be able to carry out corresponding investigations by some other method of producing the transient voltage, and thereby being able to determine exactly the amount of energy existing at the spark-gap.

A most interesting paper we have in the next paper, that by Dr. Whitehead, which I consider as extremely valuable and important at present. I may say, indeed, that we had intended to make the same investigation, even assembling apparatus of the same kind, a conductor in the center of a tube, and measuring the beginning of the breakdown by an electroscope. We expected to carry that investigation a little further, that is, to lower air pressure, so as to study more carefully the effect of higher altitudes, since we know that transmission lines at the present time extend to altitudes where the air pressure is appreciably reduced.

There is only one point in Dr. Whitehead's paper, concerning which I do not agree with him, and that is his opinion that the explanation of the apparently greater breakdown strength of air with small wires cannot well be given by the assumption of the zone of condensed air around that wire. We know, and it can easily be shown physically, that all solids are surrounded

by a zone of condensed air, and a rough calculation will show that the densities of this air at the immediate neighborhood of the conductor, by gravitational or molecular attraction, may reach considerable values. This phenomenon of the great increase of disruptive strength of air close to the solid terminals I observed and gave the explanation, that it is due to the condensed layer of air, some years ago, I believe in the paper which I read on disruptive strength before the Institute in 1893. There I found that in testing very small air gaps the disruptive strength very greatly increased, beyond that observed in the case of larger air-gaps between parallel plates.

As we know, Professor Ryan has very carefully looked into this effect, and in his paper of 1904 gave it a numerical value. I believe it would be very interesting, first, to take his numerical value of the layer of condensed air, and reduce Dr. Whitehead's tests by this assumption, thereby seeing whether we do not get a greater constancy, and then, inversely, from the data of this test, calculate how thick a layer of condensed air we have to assume to get constant break-down strength of the air. It is reasonable to assume that the layer of air is not the same, but decreases with decreasing diameter of the wire, due to the effect of divergence.

If there exists such a layer of condensed air, the result would be that the initial break-down occurs, not at the surface of the conductor, but at a small, though finite distance from the conductor surface, and with the increasing voltage the break-down extends outwardly, but also extends inwardly towards the conductor, and at a second higher voltage reaches the conductor.

This gives a second point in the curve where a change of the phenomenon might be expected to occur. It is very interesting to realize that with our increasing knowledge of the phenomena of disruptive strength, we are more and more impressed with the similarity of the electro-static strength, and its laws and phenomena, with the laws and phenomena existing in the case of mechanical forces, as pointed out also by Dr. Karepetoff. Only I do not agree that the electrostatic phenomena are simpler than the mechanical, due to the absence of shear, but there is very good evidence which makes it probable that electrostatic shear also exists, because at the edge of the electrostatic field, where the electrostatic field very abruptly changes, for instance, at the edge of two parallel plates, there is a very much greater disruptive force; although the potential gradient would be the same, and there is some evidence qualitatively, though not sufficient quantitatively, that not only the disruptive potential gradient, but also the abrupt variation of the potential gradient causes a breakdown. This was discovered first in the old Ferranti system in London, England, in bygone ages, when the cables had the unhappy habit of breaking down at the edge of the insulation—where there is an abrupt change in the electrostatic field, that is an electrostatic shear, and it is so well known

in the industry that we always carefully avoid abrupt changes of the electrostatic field, for instance, at the end of lead covered cables taper the field, etc. Experience has shown that if we allow too sudden variations of the static field, we break the insulation down, although the insulation is just as thick as where the field is uniform.

Originally when electrostatic phenomena were first investigated, they did not appear to agree with a constant breakdown strength of air, but gradually the phenomena lined themselves up in the direction of law and order, pointing towards a definite strain which air will stand, and beyond that will break down, and what we here are mainly interested in is the range beyond the break down, that is the phenomena beyond the electrostatic elastic limit of insulating material, where the phenomena have ceased to be reversible and become irreversible. It is the same thing in mechanical engineering, and we shall listen still to a paper dealing with an analogous problem in the mechanical force. This is an extremely interesting field, but the difficulty of exploring it is the same as in the case of almost all phenomena—you never find in nature a clear cut case of the action of one phase or one form, you always have it complicated by numerous other conditions, forces or phenomena which are existing as secondary actions, and practically most of the work of the electrical engineer and other engineers consists of a very simple calculation of the theoretical condition, and then he must calculate and estimate the secondary actions which modify, and sometimes entirely obscure the primary action of the phantom apparatus under phantom conditions.

The most important secondary actions in electrostatic phenomena are:

First, the phenomena of the effective terminal. That is, when we have electrostatic fields, the terminals of the field are not the solid terminals, the needle points or spheres, but are made up of that space surrounding the solid terminals within which the air or space is broken down, has passed beyond its elastic limit and is more or less conductive. Between needle points, even at extremely low voltages, the break down strength is exceeded at the points, nevertheless the spark discharge does not occur until much higher voltages are reached, and when it occurs it is not a discharge between needle points, but between these effective terminals, these approximately spherical spaces of conducting or ionized air.

The study of that phenomenon mathematically is rather difficult; is not as simple as it appears. We can easily consider the electrostatic field with its force lines and equi-potential surfaces between needle points or spheres, and then see at a given voltage what is the equi-gradient surface which corresponds to the break-down of air, and all the air space inside of this surface would become conductive. But as soon as the space becomes conductive up to the equi-gradient surface, the equi-gradient

surface becomes an equi-potential surface, while it is not an equi-potential surface in the original electrostatic field. That means the distribution of the lines of force changes and the entire field changes and the problem is to find that equi-gradient surface which at the same time is an equi-potential surface, and has the particular numerical value of the break down strength of air, and that is rather a more difficult problem.

The second phenomenon is the layer of condensed air which surrounds the solid material. The result is that the disruptive strength at the surface of the terminal is different from what it is in the space at some distance. At atmospheric pressure it is very much higher. The result of that would be, as I stated, that the initial break-down occurs at a voltage corresponding to, not the break-down gradient at the conductor surface, but at the space some distance away, or, in other words, it occurs when the ratio of the electrostatic gradient to the density of the air has reached the maximum at some point at some distance from the conductor. This also requires further theoretical investigation, which probably can be done, because we know the law of gravitation, and the gas laws, and the layer of condensed air could be calculated.

When you have electrostatic forces acting, the phenomena may be expected to be complicated still further, as Dr. Kennelly pointed out, by the electrostatic attraction, which changes the density of the layer of air and its volume.

Lastly, and one feature which we usually overlook, is the resistance of the conducting space of the effective terminals. It is not correct to say that the space within which the air is broken down and which forms the effective terminal, is a perfect conductor, but it has some resistance, and therefore quite considerably modifies the phenomena. To illustrate it by the discharge between needle points—we have a discharge occurring between these effective conductors, spherical spaces of ionized air, but these spaces are not perfect conductors—they have a certain resistance, and the resistance has the characteristic of gas resistance, that is, it increases enormously with decreasing current density. Now, the current density depends on the size of the conducting terminals, the volume which has to be ionized, and also on the frequency, and you see, then, within this range, until you have reached so large conducting spheres, effective terminals, that the amount of current required for ionization is large enough to give a negligible resistance, the frequency as well as other features, have no effect. That is very markedly shown in the striking distance curve between needle points. Theoretically, we can calculate it, allowing for the effective terminals, the ionized air space, and no matter what allowance we make we can easily show that the striking distance between needle points should be a straight line going through the origin. Now, the actual curve, as we found it by test, is given in the paper in the 1898 TRANSACTIONS, at 125 cycles; it differs from the

straight line at lower voltages. More recent tests at 60 cycles seem to show a curve in which the deviation from a straight line extends to somewhat higher voltages, and there seems to be some evidence which makes it probable that at extremely high frequencies, 100,000 cycles, the curve remains straight practically down to zero, that is, is the true theoretical curve. The cause of this deviation from the true theoretical curve seems to be the resistance of the effective terminals which, within that range, are still so small that the current consumed by them is sufficiently low to give a resistance, consuming a voltage comparable to the voltage between the needle points. At higher voltage the space ionized is so large and the current absorbed is so great that the effect has disappeared. That is another secondary phenomenon which requires consideration.

Again, we really do not observe the break down voltage, or the elastic limit of air directly, but always indirectly by different methods, and there is no evidence that the point we observe by different methods is the same point. We get it by the disruptive discharge. We get it by observing the beginning of ionization, as described in Dr. Whitehead's paper. We get it by the corona. We get it by measuring the energy loss in the conductor as in Mr. Mershon's paper or Mr. Ryan's paper. Then we get it by the increase of capacity of the conductor, at the voltages where the corona spreads out and increases the effective conductor. There is no reason why the different methods should really give you the same point. As soon as the air begins to break down anywhere in space, an irreversible process occurs. The energy consumed by it is not returned. It means at that point the energy loss in the electric system must appear. If we could measure the beginning of the energy loss exactly, which is an extremely difficult problem, we could show the beginning of the energy loss, the beginning of the break down.

As there is a layer of condensed air, that initial break down occurs at some distance from the conductor, and the conductor, therefore, is surrounded by a zone of conducting air which is separated from the conductor by a layer of compressed and insulating air. There is no conduction of current from the conductor into the ionized air region until a higher voltage is reached, when the zone of disrupted air spreads to the conductor and current begins to flow into the zone. It appears possible that the point where the capacity of the conductor increases is not the point where the initial break down occurs, but is the point where the zone of broken down air gas spread up to the conductor and reached it.

It is curious to note that there are also two visible steps in the luminosity which are quite sharply marked, and are also apparently sharply distinguished by their chemical action. First appears the glow, the noiseless or silent discharge. Perhaps this is the break down at some distance from the conductor, not at the conductor—while the air at the conductor still is insulating, but

at some distance therefrom has broken down. This does not appear at needle points, where the break down must occur at the beginning, but it appears very markedly at plane surfaces. Then at higher voltage, the blue glow is superseded by violet streamers, which are noisy and are interrupted, intermittent, and appear to represent conduction of current, when that ionized layer of air has reached the conductor. When conduction occurs into the space, that conduction, following the gas laws, has the effect that as soon as current begins to pass locally the resistance at the space falls, a discharge occurs, the voltage disappears and the current disappears, so by the laws of gas conduction the current must be intermittent and must always be a localized expenditure of energy as a spark or streamer. At this point, apparently, the chemical action changes. Where we have the blue glow, the energy seems to be sufficient to dissociate the oxygen molecules, but not the nitrogen molecules, and ozone formation takes place. As soon as you see these violet streamers, not only the oxygen molecules, but also the nitrogen molecules split, and you get nitric-oxide, but less ozone, because at the high temperature of that streamer discharge the ozone is broken up, so that there seems to be a sharp dividing line. Below that the blue discharge produces ozone, above it the streaming discharge or brush is intermittent, and of different color, noisy, and seems able to fix nitrogen.

The whole subject is an extremely interesting one, and what I have said here I do not want to have taken as conclusive evidence, as the entire field is altogether too new to accept final conclusions. This is only my present personal opinion of what, from the evidence, appears to be probable. We must all be governed by further evidence, which may and probably will change our opinions more or less.

John B. Whitehead: Before answering the questions which have been asked in connection with my paper, I want to say a few words in general comment on the three papers which have been presented at the morning session.

These three papers all deal with the effects of high voltage on insulation. Each of the papers presents a set of experimental results on this perhaps most important of all electrical questions. All of them fail, however, to explain the observations in terms of simpler phenomena or physical laws at present understood. Nor do the few suggestions of explanations which are offered coincide either in point of view or language of expression. There is here then a sharp indication of present uncertainty surrounding these highly interesting phenomena. The uncertainty, however, is by no means as great as may appear from this confusion. The phenomenon of spark discharge in all its manifestations has been a subject of study by experimental physicists for many years. As a result of this study the ionic theory has not only paved the way for most fruitful investigation, but has been finally established as a medium through which

many electrical manifestations now receive their explanations in terms of the laws of simple mechanics. For no set of phenomena is this more true than for the spark discharge in gases. While there are still many phenomena which have not yet been brought into perfect accord, those which have been studied most widely show conclusively that for a proper understanding of the conditions governing the break-down of insulation whether gaseous, liquid or solid, the way must be through the knowledge of the properties of ions which has been already gained. These comments are suggested by the mode of interpretation used by Messrs. Hayden and Steinmetz in discussing their results. We are to be congratulated upon the presentation of so careful and accurate a set of experiments in a field so little understood. The conclusions drawn from the experiments by the authors, however, invite some comment.

Disruptive discharge is said to require a definite minimum amount of energy. The laws of spark discharge in air which may be said to be firmly established, explain the phenomena in terms of motion of gaseous ions, *i.e.*, charged particles, acted on by electric force. These ions have mass, and therefore acceleration and momentum when in an electric field. The laws of motion and impact of the simple mechanical system thus presented lead in many cases to complete explanation. Spark discharge is the result of secondary ionization or the collision of a charged particle moving under electric force with a neutral molecule, thus breaking up the latter into new ions and so furnishing the conductors for the discharge. Since the free ions have mass they require time to attain speed. If the electric force is transient and of sufficiently short duration the ion may remain practically unaffected. The study then of the phenomena of transient voltages should be extended to that of the shape and duration of the voltage impulse, *i.e.*, the integrated product of intensity and time in relation to the known properties of gaseous ions. Even granting that the initial discharge voltage of the experiments is properly deduced from the ratio of turns, this value cannot exist for more than an infinitesimal time and the appendix concludes that the shortest and longest time durations of a pulse are in the ratio 1 to 100. It is concluded that the discharge does not instantly follow the application of voltage, although the observations leading to this conclusion are not described. It is also stated that during the interval energy is being supplied to the dielectric, and relations are deduced between energy and sparking distance for air and oil, as given on page 770. Although the observed points in the two cases fall on curves of different shape they are assumed to have the same equations, and although the energy is measured at the transformer primary, it is assumed to be a basis of comparison for the secondary spark-gaps. It would be interesting to know what part of the energy delivered to the magnetic circuit is regained upon opening the primary circuit. It would also be

interesting if the authors would present a conception of the mechanism by which a dielectric accumulates energy leading up to disruptive discharge.

Taking up the points that were brought out in connection with my own paper, the first question was that of Mr. Mershon as to the point on the voltage wave at which the corona ceases in relation to the point at which it starts, and he raised the question as to just how you could expect the corona to stop at a lower voltage than that at which it started. The indication is that there is only a small lag, if any, in the point of disappearance of the corona. The corona, however, is a source of heat in the gas, and the raising of temperature has the effect of lowering the corona voltage.

Regarding Mr. Thomas' questions—first, the conditions at the ends of the tube: The wire is carried through a cylindrical metal bushing set in a glass receptacle of the shape very much as indicated in the drawing on page 1063. There is no observation of spark discharge, no corona nor anything else indicating ionization at this point, occurring before that on the length of wire within the tube. If you carried the wire through a rubber or other insulating bushing, ionization would first set in at that point, and would spread to some extent along the wire inside of the tube. The variation of electric field at the end of the tube is quite marked, of course, outside the tube, but does not extend to the region inside for any considerable distance. As soon as corona forms, it is very evident that no error is introduced on this account. The whole apparatus was, of course, enclosed with the idea of conducting any ionization that was generated out through the gap leading to the electrode. I think there was no error on this score.

With reference to the question as to whether in a small wire rapid change of gradient at the surface would explain any of these phenomena: The potential gradient does change very rapidly; however the distances within which the potential gradient varies widely are very much greater than mean free paths of the molecules and ions.

P. H. Thomas: You did not catch my point—the question is whether the volume of air which was subjected to something like the critical strain was not greater in the case of the large wire, not that the mean free path was involved, but the surrounding presence of supporting ionized air might prevent the overwhelming of the very narrow zone there, very narrow particles, with reference to the free paths.

J. B. Whitehead: I am not sure that I get the idea. Ionization in this case is a sharply cumulative effect. As soon as you get a region where there is this secondary ionization, when this second ionization starts, it is a continuous thing, and if you attempt to explain it by any relation between the mean free paths of the ion or the molecule, and the variation in diameter of the wire, there is the widest kind of discrepancy. I have

given the figure 10^5 in the paper showing that the two quantities are of different orders of magnitude.

Referring to the question as to the state of the air as it leaves the wire, whether it has positive or negative ions—I think Mr. Lincoln asked a similar question—a gas ionized in this way has both positive and negative charges—the point of initial break-down will be observed by charging the electroscope either positively or negatively. The only differences which come in are in the shape of the discharge curve of the electroscope. These differences are to be expected in view of the known fact of the difference in the rates at which the positive and negative ions move in the gas and the different rates at which they diffuse. The point of break-down can be observed with either kind of ion. I have not worked with any other gas than air.

The question as to the positive and negative corona is taken up in the paper, rather briefly, and I have pointed out that there is no apparent difference in the positive and negative corona unless it be possibly the somewhat greater brightness and sharper definition of one. I am not prepared to say that there was any noticeable difference.

As to the relation of initial ionization to the following arc, the corona starts evenly, as you are, of course, aware. As you go on increasing the voltage you will finally get to either a spark or an arc. Now then, just what this range of voltage is will depend on the relative diameters of the inner wire and the tube. The potential gradient between a tube and the central wire depends upon the diameter of the wire in such way that under some circumstances an increase in diameter will mean a lowering of the electric intensity and under other conditions it will mean an increase in the electric intensity. With the increase in corona diameter, resulting from increased voltage, when the corona reaches a point so that any further increase means an increase of intensity the spark or arc follows.

Dr. Kennelly and Dr. Steinmetz have each suggested that an increase due to pressure in the neighborhood of a small wire may offer a means of explaining the increase of electric intensity of corona and break-down. I am not quite sure that I grasp Dr. Steinmetz's idea, in that I cannot see why you should expect any difference between the case of small and large wires. Professor Kennelly's idea is, of course, a possible one, and there is no difficulty about imagining such a thing to occur. I would say, however, that I have made efforts to observe any increase in pressure in the neighborhood of these wires by optical means —the increased density of this air in its relation to the neighboring portions, permits the use of a very simple optical method of observation. Such experiments were negative in my case, although I cannot say I think that is any conclusive proof that some such increase of pressure may not explain the observed facts. Since we are dealing with extremely small distances, and I am not sure that even with the optical method I have used the

layer would be sufficiently thick to manifest itself in this way. The test is known to physicists as the "Schlieren" method.

Professor Creighton made some comments as to the auto-ionization of the air and the necessity of removing ions. I do not know the word auto-ionization. Ions may be generated by secondary ionization, as in coronæ, and recombine very promptly; the air is then to all appearances in quite the same state as it was before secondary ionization or coronæ set in. This is shown very well by the sharpness with which the corona stops and by the absence of any after effects of ionization. There are always a certain number of free ions in the air, and these ions account for the small conductivity which air has. If you generate ions by some external means, and put them in the air, it simply means you can get a greater leakage current, but the presence of these ions does not in any way hasten or lower the point at which secondary ionization steps in, it simply increases the leakage current. There are numerous ways of removing free ions from the air; the use of glass wool, or crude raw cotton and various materials of like nature, through which the air can be drawn to a perfectly pure state, so far as ionization is concerned, but it will always have a certain extremely small number of free ions. The natural conductivity of the air is entirely explainable on this basis. For reasons which will be found in the remarks I have just made, I do not think Professor Ryan's suggestion, as well as I was able to gather it from hearing his letter read in the meeting, that there may be a difference between indoor and outdoor ionization, offers an explanation of the discrepancies that he is calling attention to. The range of natural ionization throughout the regions which have been investigated all over the earth, is about in the ratio of 1 to 4, and as I have said, the presence of more or less free ions in the air, simply increases conductivity, but I do not believe under any circumstances it would hasten the point at which secondary ionization, spark discharge, or corona would start.

Mr. Mershon has asked the effect of the wave form on the observations. The discussion of the wave form is given in the paper, showing the relation of maximum to effective values, and also in the reference to the curve Fig. 5. It is possible to observe the corona very close to the peak of the wave, and it is so sensitive that it was possible by careful voltage adjustment to pick up the three little peaks by the stroboscopic method with intervening dark spaces corresponding to the dimples.

As to Conclusion 10, that the corona has high conductivity and most of the loss takes place beyond it, that is based on the results given in the paper, where it is shown that the intensity at the edge of the corona is the same, practically the same, differing from it by a small amount, as that of a solid wire of the same diameter, and if that is the case it is a fairly reasonable assumption that the corona has high conductivity, and marks the limit at which ionization takes place.

In calling attention to Mr. Mershon's method of measurement I have been led by the process of elimination of all other explanations of the discrepancies between our results. Mr. Mershon has pointed out that his critical point is not necessarily the same as my own, but I am unable to see any other explanation than that of corona and break-down for the sharp, upward bend of his curves. I am unable to think of any means, also, by which there is a possible loss through the air below this point.

It has been suggested by several that laboratory methods present conditions different from those obtained outside and that this may be an explanation of some of these differences. I should be interested to hear some one suggest some means or method by which a loss could take place through air at voltages below those at which it actually breaks down.

M. A. de Chatelain (by letter): The writer and his associate, Professor V. F. Mitkevitch, were led to the question of corona formation and the accompanying losses in connection with the question of possibility of high-tension power transmission in the vicinity of St. Petersburg, Russia.

Laboratory experiments were performed on cylindrical conductors of different diameters, placed at different distances from each other. In view of discrepancies in the values of the critical voltage, as given by Messrs. Scott, Mershon, Ryan, Kapp, and Berg, among themselves and with our results, Professor Mitkevitch was led to investigate the matter theoretically. Based upon J. J. Thomson's researches on conductivity of gases he has found the following formula for the critical voltage:

$$E_{eff} = 35 \frac{H}{273+t} \cdot r \log_{10} \frac{d}{r} \text{ (in kilovolts)}$$

where

H is the barometric pressure in mm. of mercury;
t is the temperature of air in degrees centigrade;
r is the radius of the conductor, in cm.;
d is the distance between the centers, in cm.

Changes in humidity did not produce any appreciable variations in results. The values calculated according to the foregoing formula were checked experimentally in the electrical laboratory of St. Petersburg Polytechnic Institute, and were compared to the results given by Professors Ryan and Kapp for the same conditions. The comparison is given in Tables I and II. It will be seen that the difference between the voltages at which the corona became visible, and those calculated according to Professor Mitkevitch's formula, are not large.

It may be appropriate to mention here that Professor Kapp's adaptation of Mershon's formula (Journal of the Inst. El. Engs., February, 1910) leads to an odd result, namely, that the critical voltage, beyond a certain limit, becomes lower with increasing diameter of conductors (see Table III).

Mr. Mershon's statement that the losses increase with the frequency led us to investigate the effect of frequency. Our results seem to indicate that the loss is practically independent of the frequency, and rather decreases at higher frequencies. Namely, we measured the losses between two parallel planes, 27 x 27 cm. each, one of which was covered with needles of the same length. The distance between the points and the opposite plane was 2 cm. The frequency was varied from 15 to 90 cycles per second. After having taken into account the necessary corrections for the capacity, etc., we found the following values of losses:

Cycles	Watts
15	56
50	54.5
90	54

TABLE I

2 *r* (mm.)	*d* mm.	Critical kilovolts Observed	Calculated*
5 (cable)	1000	65	60
11 (cable)	"	120–125	115
11 (tube)	"	125–130	115
14.3 (tube)	"	145–150	141

*Formula Professor Mitkevitch

TABLE II
CRITICAL KILOVOLTS

d mm.	2 *r* = 10 mm. Ryan	Kapp	Mitke-vitch	2 *r* = 15 mm. Ryan	Kapp	Mitke-vitch	2 *r* = 20 mm. Ryan	Kapp	Mitke-vitch
500	143	82	98	180	89.5	135	212	92.5	165
1000	165	94	110	209	104	155	250	109.5	195
2000	187	106	125	236	119.5	177	287	125.5	225
3000	200	114	135	256	128	190	310	135	240

TABLE III

d mm.	2 *r* mm. 5	10	15	20	25	30	50	100	150	200
2000	79.3	106	119.5	125.5	128.5	131	130	119.5	—	—
10000	98	136	154	164	171	172	177	169	163	156

Addenda to a paper presented at the 27th Annual Convention of the American Institute of Electrical Engineers, Jefferson, N. H., June 27–30, 1910.

DISRUPTIVE STRENGTH WITH TRANSIENT VOLTAGES

BY J. L. R. HAYDEN AND CHARLES P. STEINMETZ

[NOTE: The following addenda have been contributed by the authors since the publication of the above paper in the PROCEEDINGS for May, 1910, and should be considered a part of that paper.]

From the table of effective duration t_0 of the high voltage impulses, given at the end of the appendix, we can derive approximate values of the striking distances as function of the time of the application of constant voltage, by substituting the values of transient striking distances, given in Tables III and IV, into the Table X at the end of the appendix.

This gives the Table XII, which is plotted in Figs. 13 to 16. As seen, the curves have a curious double bend. This however may be apparent only, and due to the constant error inherent in the method of test. Producing these twisted curves, until they strike the horizontal line of constant voltage striking distance, gives the minimum time required for the application of voltage, to reach full striking distance. However, in most cases the transient striking distance curves in Figs. 13 to 16 do not extend to high enough values to get their point of intersection with the horizontal line of constant voltage with any degree of accuracy. Estimating these points of intersection, gives the values recorded in Table XIII and plotted in Fig. 17, which can approximately be expressed by the equation:

$$e^{0 \cdot 8}\, t_0 = 37.8$$

These values however are very uncertain, as stated above, and further investigation of these phenomena is very desirable.

TABLE XII
Striking Distances with Transient Voltages
(From Tables III, IV and X)

	kv.									
	15	$t=$	0.97	3.54	9.10	12.6	14.5	15.8	$\times 10^{-3}$	∞
Air: Needles......		$d=$	0.41	0.75	0.98	1.10	—	1.22		1.26
Spheres......			0.075	0.18	0.29	0.36	0.38	0.40		0.43
Oil: Needles......				0	0	0		0		0.03
Spheres......				0.026	0.042	0.050		0.066		0.07
	30	$t=$	0.48	1.77	4.55	6.3	7.2	7.9		∞
Air: Needles......		$d=$	0.48	0.88	1.47	1.89	—	2.31		2.73
Spheres......			0.093	0.235	0.47	0.66	0.73	0.78		0.95
Oil: Needles......				0	0	0.016		0.054		0.17
Spheres......				0.033	0.061	0.071		0.098		0.16
	45	$t=$	0.32	1.18	3.03	4.2	4.8	5.3		∞
Air: Needles......		$d=$	0.50	0.97	1.77	2.44	2.68	3.14		4.45
Spheres......			0.106	0.265	0.57	0.90	1.02	1.16		1.54
Oil: Needles......				0	0.024	0.064		0.21		0.48
Spheres......				0.036	0.071	0.087		0.121		0.27
	60	$t=$	0.24	0.88	2.27	3.15	3.6	3.95		∞
Air: Needles......		$d=$	0.515	1.02	1.95	2.88	3.32	3.88		6.83
Spheres......			0.11	0.285	0.65	1.07	1.24	1.49		2.19
Oil: Needles......				0	0.036	0.155		0.40		0.98
Spheres......				0.037	0.078	0.099		0.133		0.375
	75	$t=$	0.19	0.71	1.82	2.5	2.9	3.2		∞
Air: Needles......		$d=$	0.52	1.05	2.06	3.22		4.5		9.8
Spheres......			0.11	0.30	0.69	1.19	1.40	1.70		2.86
Oil: Needles......				0	0.049	0.235		0.54		
Spheres......				0.037	0.083	0.107		0.144		0.48
	90	$t=$	0.16	0.59	1.52	2.1	2.4	2.6		∞
Air: Needles......		$d=$	0.525	1.06	2.13	3.45	4.05	5.02		13.0
Spheres......			0.11	0.31	0.715	1.29	1.50	1.87		
Oil: Needles......				0	0.055	0.28		0.64		
Spheres......				0.037	0.088	0.114		0.157		
	105	$t=$	0.14	0.51	1.30	1.8	2.1	2.3		∞
Air: Needles......		$d=$	0.53	1.07	2.19	3.60	4.46	5.39		16.3
Spheres......			0.11	0.32	0.73	1.35	1.56	1.94		
Oil: Needles......				0	0.061	0.30		0.71		
Spheres......				0.037	0.092	0.120		0.163		

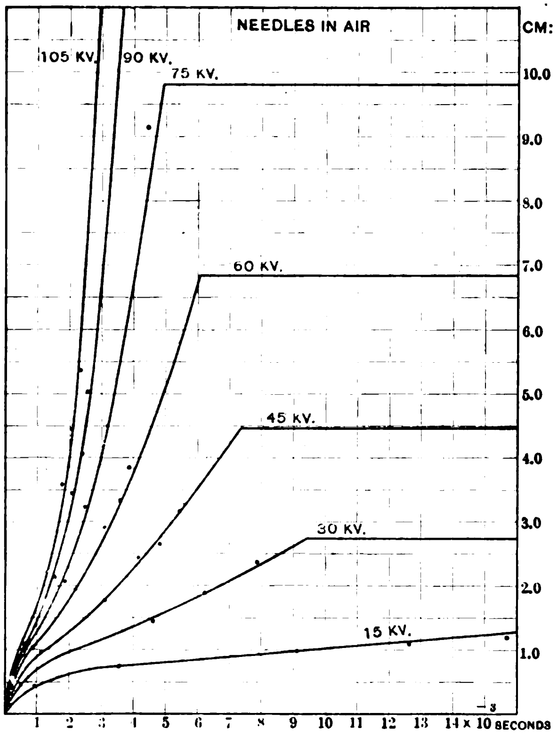

NEEDLES IN AIR
CM:
105 KV.
90 KV.
75 KV.
60 KV.
45 KV.
30 KV.
15 KV.
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 x 10⁻³ SECONDS

FIG. 13

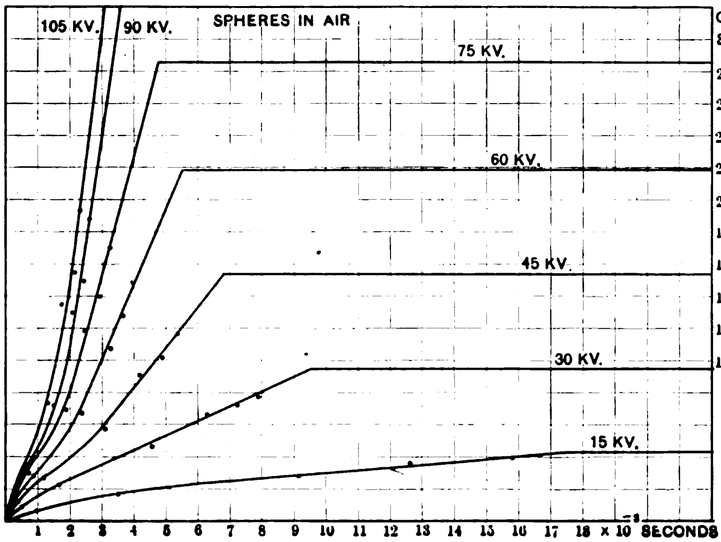

SPHERES IN AIR
CM.
105 KV.
90 KV.
75 KV.
60 KV.
45 KV.
30 KV.
15 KV.
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 x 10⁻³ SECONDS

FIG. 14

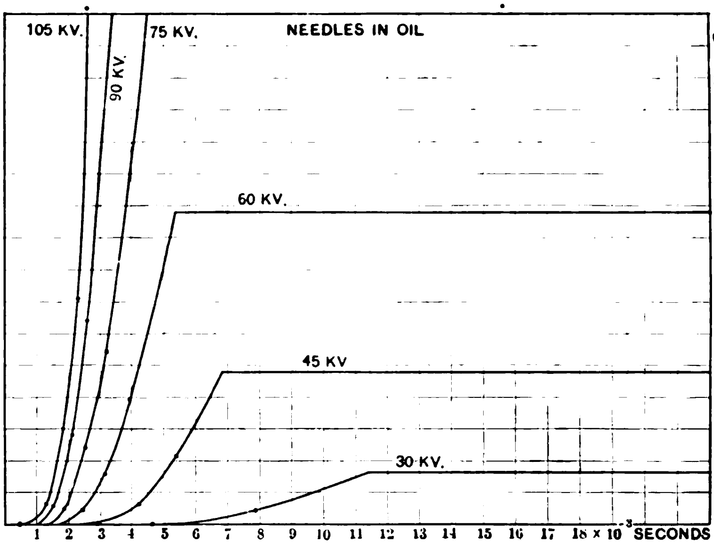

NEEDLES IN OIL
105 KV.
90 KV.
75 KV.
60 KV.
45 KV
30 KV.
CM.
SECONDS

FIG. 15

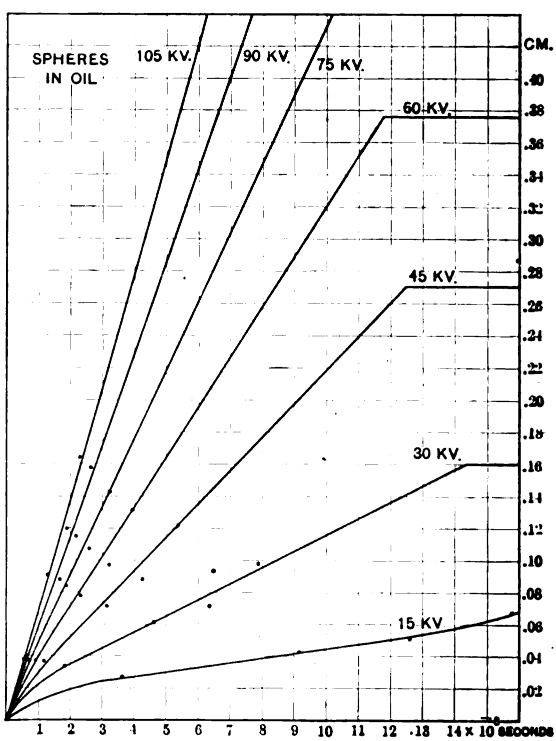

SPHERES IN OIL
105 KV.
90 KV.
75 KV.
60 KV.
45 KV.
30 KV.
15 KV.
CM.
SECONDS

FIG. 16

TABLE XIII

Minimum Time of Standard Striking Distance

e Kv.		Air Needles	Air Spheres	Oil Needles	Oil Spheres		Avg.	Calc.
							$\times 10^{-3}$	
15	$t_0 =$	16.8	17.5		17	$\times 10^{-3}$	17.1	17.2
30		9.5	9.5	11.3	(14.4)		10.1	9.9
45		7.4	6.8	6.9	(12.4)		7.0	7.2
60		5.9	5.5	5.3	(11.7)		5.6	5.7
75		4.9	4.8		(11.2)		4.85	4.75
90		(4.4)					(4.4)	4.1
105		(4.2)					(4.2)	3.6

$$t_0 = \frac{37.8}{e^{.8}}; \quad (e^3 t_0)^2 = \frac{74 \times 10^6}{t_0^3}$$

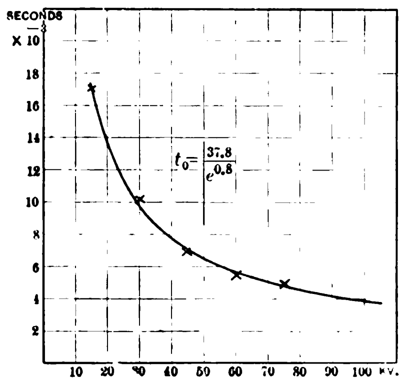


FIG. 17

A paper to be presented at the 253d Meeting of the American Institute of Electrical Engineers, New York, November 11, 1910.

INTERPOLES IN SYNCHRONOUS CONVERTERS

BY B. G. LAMME AND F. D. NEWBURY

Synchronous converters with interpoles have been used but little in this country, but they have been built to some extent in England and on the continent of Europe, principally by companies which are either directly connected with or very closely allied to the companies which have manufactured the great bulk of the converter apparatus installed in this country. Considering that interpole generators and motors came into extensive use in this country at about the same time as in Europe, the question would naturally be raised why interpole converters have not come into similarly extensive use, especially as the principal designers of converters in this country are in direct touch with the designers of the commutating pole converters in Europe. The reply might be that the introduction of any new type of apparatus is a relatively slow process; but, on the other hand, interpoles on direct current generators and motors came into general use in a relatively short time, especially so in railway motors. This indicates that there has been a more or less pressing need for interpoles in certain classes of apparatus and the greater the need for the change the quicker was the change made. Any important change in design or type must be justified by engineering and commercial reasons, such as improved performance greater economy, or lower cost. In the railway motor, placed under the car, and more or less inaccessible, improved operation at the brushes and commutator, when equipped with interpoles, represented a pressing reason for the change in type, although the cost and efficiency were not appreciably changed. In the direct-current generator with the modern tendency toward higher speeds with lower cost, the interpoles represented a

practical necessity. This has been recognized for several years and the change to the interpole type has been made as rapidly as circumstances will permit. Also, in variable-speed direct-current motors interpoles have been in general use for a number of years, simply because the interpoles represent a very definite improvement in a number of ways.

New types of apparatus should only be introduced where they represent some distinct improvement or advance over existing types. Where a new type does not represent such improvement and is simply introduced to gratify a personal whim of the purchaser, or desire on the part of a manufacturing company to produce something different from other companies, the new apparatus, as a rule, will not advance quickly into public favor since there is no real necessity for it.

It is therefore a question whether the slowness in the introduction of interpoles in synchronous converters is due to lack of sufficient advantages, or American engineers do not sufficiently appreciate their advantages. There appears to be room for wide differences in opinion on this subject. The synchronous converter and the direct-current generator are two quite different machines, in their characteristics, and no one can say off hand, that interpoles will give the same results in both. In the following is given a partial analysis of the conditions occurring in the two classes of machines, which will indicate wherein interpoles are of greater advantage on direct-current generators than on converters.

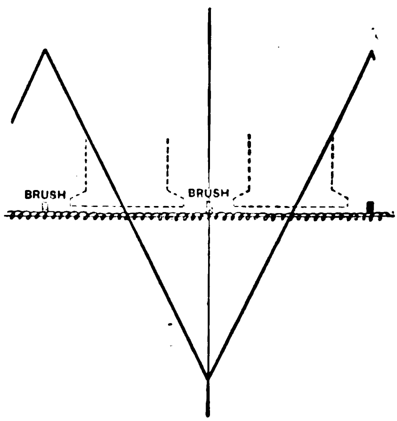


Fig. 1

Taking up first, the direct current generator, it may be considered as containing two sets of magnetizing coils, namely, the armature and the field windings. Considering the armature winding alone, the magnetomotive force of the armature winding has zero values at points midway between two adjacent brush arms or points of collection of current and rises at a uniform rate to the point of the winding which is in contact with the brushes. This is illustrated in Fig. 1. Therefore the armature winding

has its maximum magnetizing effect or magnetomotive force at that part of the core surface where the winding is directly in contact with the brushes. However, the magnetic flux set up by the armature winding will not necessarily be a maximum at this point, as this depends upon the arrangement of the magnetic or other material surrounding the armature. If this point occurs midway between two field poles, then, while the magnetizing effect is greatest at this point, the presence of a large air-gap at this same point may mean a relatively small magnetic flux, while a much higher flux may be set up by the armature winding at the edges of the adjacent field poles. In the usual direct-current generator construction without interpoles, the position of commutation is almost midway between two adjacent poles and therefore the point of maximum magnetomotive force of the armature is also practically midway between poles. The absence of good magnetic material over the armature at this point serves to lessen the magnetic flux due to the armature magnetizing effect, but even with the best possible proportions there will necessarily be a slight magnetic flux set up at this point. While this field is usually of small value, yet unfortunately it is of such a polarity as to have a harmful effect on the commutation of the machine. During the operation of commutation, the coil which is being commutated has its two terminals short-circuited by the brushes. If this short circuited coil at this moment is moving across a magnetic flux or field, it will have an e.m.f. set up in it which will tend to cause a local or short circuit current to flow. Such a current is set up by the flux due to the armature magnetomotive force described above and unfortunately this current flows in such a way as to give the same effect as an increased external or working current to be reversed as the coil passes from under the brush. In other words, the e.m.f. set up in the short circuited coil by the above field adds to the e.m.f. of self induction in the coil due to the reversal of the working current.

Another cause of difficulty in the commutation of a direct current machine is the self induction of the armature coils as they individually have the current reversed in them in passing from one side of the brush to the other. Each coil has a local magnetic field around itself, set up by current in itself and its neighboring coils. The value of this local magnetic field depends upon the arrangement of the winding, the disposition of the magnetic structure around the coil, the ampere turns, etc. During the

act of commutation, that part of the local field due to the coil which is being commutated must be reversed in direction. It is therefore desirable to make the local field due to any individual coil as small as possible. This means that the number of turns per coil should be as low as possible, the amperes per coil also should be as small as possible, while the magnetic conditions surrounding the coil should be such as to give the highest reluctance. By the proper arrangement of the various parts, it is usually found that the e.m.f. of self induction, due to the reversal of the coil passing under the brush, can be made of comparatively small value so that, if no other conditions interfere, good commutation could be obtained under practically all commercial operating conditions. However, the magnetic field between the poles set up by the armature magnetomotive force as a whole, as described above, adds very greatly to the difficulties of commutation. If the armature magnetomotive force, or the field due to it, could be suppressed, then one of the principal limitations in the design and operation of direct-current generators would be removed, and the commutation limits would be greatly extended. Or, better still, if a magnetic flux in the reverse direction were established at the point of commutation, then the e.m.f. set up by this would be in opposition to the e.m.f. of self induction of the commutated coil and would actually assist in the commutation.

This latter is what is accomplished by interpoles. When these are used the brushes on the commutator are so placed that the short circuited or commutated coils are directly under the interpole. Consequently, the maximum magnetomotive force of the armature is in exact opposition to that of the interpoles. Therefore, the total ampere turns on the interpoles should be equal to the total ampere turns on the armature in order to produce zero magnetic flux under the interpole or at the point of commutation. But, for best conditions there should not be zero field, but a slight field in the opposite direction from that which the armature winding alone would produce. Therefore, the magnetomotive force of the interpole must be greater than that of the armature by an amount sufficient to set up a local field under the interpole which will establish an e.m.f. in the short circuited coils opposite to that set up by the commutated coils themselves and practically equal to it. The excess ampere turns required on the commutated poles is therefore for magnetizing purposes only and the amount of extra ampere turns will depend upon the value of the commutating field required, depth of air-gap under

the commutating pole, etc. The commutating field required is obviously a function of the self induction of the commutated coil and evidently the lower the self induction the less commutating field will be required. It is evident therefore that the commutating field under the commutating pole bears no fixed relation to the armature ampere turns or to the main field ampere turns, but is, to a certain extent, dependent upon the proportions of each individual machine.

It is evident that the magnetomotive force of a given armature varies directly with the current delivered, regardless of the voltage. Therefore, that part of the interpole magnetomotive force which neutralizes that of the armature should also vary directly in proportion to the armature current. Also, the self induction of the commutated coils will vary in proportion to the armature current carried, and therefore the magnetic field under the interpole for neutralizing this self induction should also vary in proportion to the armature current. It is therefore obvious that if the main armature current be put through the interpole winding, the magnetomotive force of this winding will vary in the proper proportion to give correct commutating conditions as the armature current varies, regardless of the voltage of the machine. This is on the assumption that the entire magnetomotive force of the interpole winding is effective at the air gap and armature, which implies an absence of saturation in the interpole magnetic circuit. In the usual construction, the interpole winding always carries the main armature current as indicated above.

One consequence of the use of the interpole is that somewhat less regard need be paid to keeping the self induction of the commutating coil at its lowest value. In consequence, there is somewhat more freedom in proportioning the armature winding, slots, etc., than in a non-interpole machine, and advantage can be taken of this in bettering the proportions for other characteristics. The conditions of design are therefore not as rigid in the interpole as in the non-interpole type.

The above description of the interpole generator has been gone into rather fully, as many of the points mentioned will be referred to again in connection with interpoles on synchronous converters.

The synchronous converter differs from the direct current generator in one very important particular, namely, it may br considered as motor and generator combined. It receives cue-

rent from a supply system the same as a motor and it delivers current to another system like a direct-current generator. The magnetomotive force of the armature winding as a motor acts in one direction, while the magnetomotive force of the armature winding as a generator acts in the opposite direction. As the input is practically equal to the output, it is evident that these two armature magnetomotive forces should practically neutralize each other, on the assumption that the armature magnetomotive force, due to the polyphase current supplied has practically the same distribution as that of the corresponding direct-current winding. Assuming that the two practically balance each other, then it is evident that one of the principal sources of commutation difficulty in direct current generators

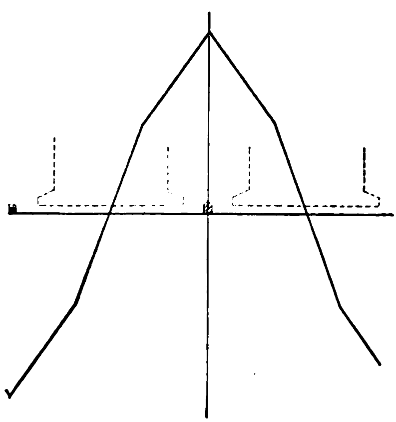


Fig. 2

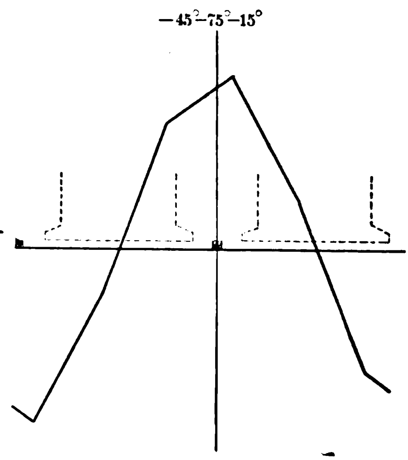


Fig. 3

is absent in the converter and therefore the limits in commutation should be much higher than those of direct-current machines.

The following diagram show the distribution of the alternating-current and direct-current magnetomotive forces on a six-phase rotary converter. The magnetomotive force distribution for the alternating-current input is plotted for several different positions of the armature. Three different positions are shown with the armatures displaced successively 15 electrical degrees. The general forms of these distributions repeat themselves for further similar displacements.

These distributions are illustrated in Figs. 2, 3 and 4. It is evident from these three figures that the peak value of the mag-

netomotive force the armature varies as the armature is rotated, as indicated by the heights of the center line in the three figures.

In Fig. 5, the magnetomotive force distribution of Fig. 2 and the corresponding direct-current distribution of Fig. 1 are both shown, but in opposition to each other. In this figure both are shown in proper proportion to each other, taking into account the alternating current amperes and the direct-current amperes output. The resultant of these two distributions is also indicated in these figures.

In Fig. 6 the distributions correspond to Figs. 3 and 1 combined and the resultant is also shown.

Fig. 7 combines Figs. 4 and 1.

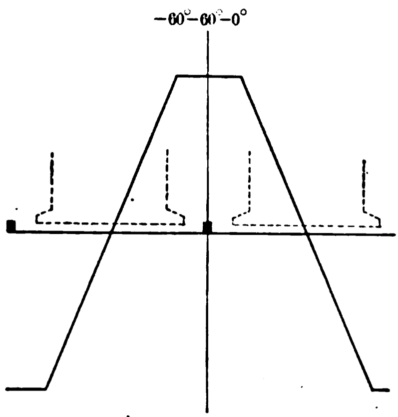


FIG. 4

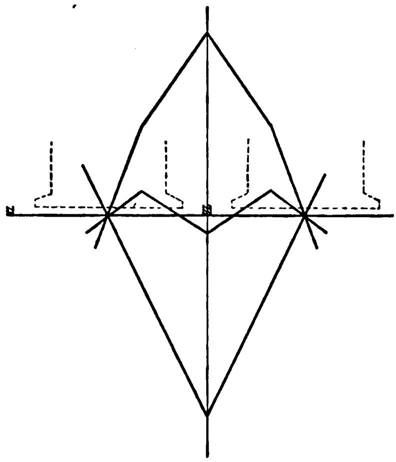


FIG. 5

It is the resultant magnetomotive force in these three figures which is important, as this is the effective magnetomotive force which tends to produce a flux or field over the commutated coil. It is evident from these figures, which are drawn to scale, that this resultant varies in height as the armature is rotated, but the maximum is only a relatively small per cent of the direct-current magnetomotive force. Therefore, it is obvious that one of the principal sources of difficulty in the commutation of the direct-current generator is practically absent in the converter, and it is also evident from this that the commutating conditions in the latter should be materially easier than in the former. This has proved to be true by wide experience in the construction and operation of converters.

In the above figures the magnetomotive forces have been plotted to scale on the following basis:

The six-phase converter winding is connected to three transformers with the so-called diametral arrangement; each of the three secondaries is connected across the diameter, or across 180 deg. points on the winding, the three diameters being displaced 60 deg. with respect to each other. Assuming the direct current in the winding as A, then the maximum value of the alternating current in any one phase of the alternating-current end will be equal to $\frac{2}{3}$ A, or 0.667 A, assuming 100 per cent efficiency. However, as the alternating-current input must be somewhat greater than the direct-current output, due to certain

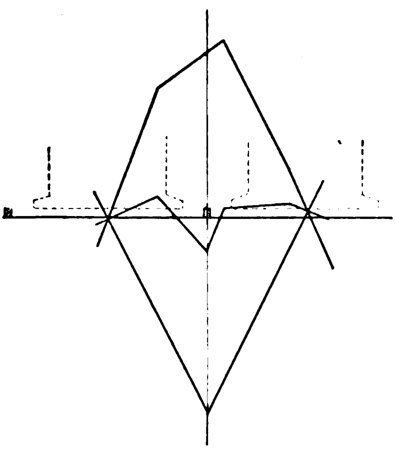


Fig. 6

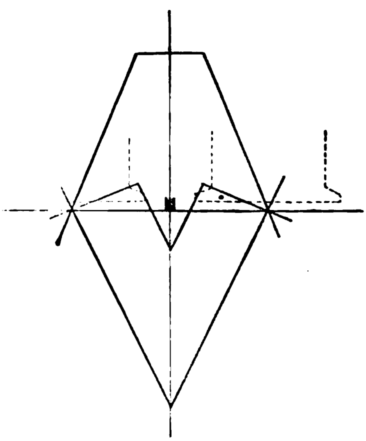


Fig. 7

losses in the machine, it is evident that the maximum alternating current in any one phase must be somewhat greater than 0.667 A. The field copper losses may be considered as part of the output of the rotary. The armature copper losess may be considered as due to an ohmic drop between the counter e.m.f. of the armature and the transformer e.m.f., and simply a higher transformer e.m.f. must be supplied to overcome this drop and therefore it does not effect the true current input of the rotary. However, the losses due to rotation, such as iron loss and the friction and windage are excess losses which represent extra current which must be supplied to the alternating-current end of the rotary. These rotational losses will usually be relatively small in a 25-cycle converter, being possibly 4 per cent or 5 per

cent in a small machine and $1\frac{1}{2}$ per cent to 3 per cent in a large machine. In the 60-cycle converters, where the iron losses are relatively higher and the speeds are somewhat higher, giving greater friction and windage, the rotation losses may be considerably greater than on 25-cycle machines. Assuming these rotation losses will be 3 per cent, then the maximum alternating current per phase $= \frac{0.667\,A}{0.97} = 0.687\,A$. The foregoing Figs. 5, 6 and 7 are worked out on this assumption of 97 per cent rotational efficiency and on this basis of minimum value of the resultant magnetomotive force of the armature at the direct-current brush is about 7 per cent of the direct-current magnetomotive force of the same wording, while the maximum value is about 20 per cent. The lower the rotational efficiency the smaller would be these values, and with a rotational efficiency of about 89 per cent, the minimum resultant would fall to zero, while the maximum value would be about 13 per cent.

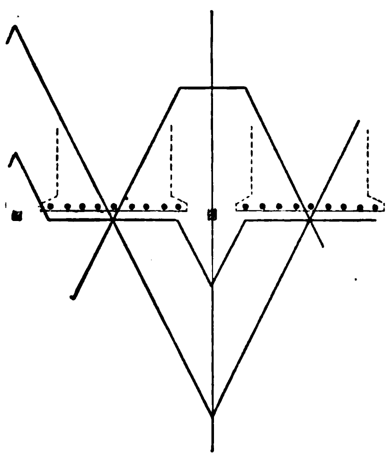


Fig. 8

The resultant magnetomotive force of a synchronous converter might be compared with that of a direct-current generator with compensating windings in the pole faces. It is generally known that such direct-current generators have much better commutating conditions than ordinary uncompensated machines. If such compensating winding on the field of a direct-current machine covered symmetrically the whole armature surface, then the armature reaction could be completely annulled, which is not the case in the converter. But with compensating windings located only in the pole faces, then the armature magnetomotive force midway between the poles could not be completely annulled, unless over-compensation is used, and the resultant would be as shown in Fig. 8, which is not quite as good as the average resultant in the converter. The commutating conditions in the converter can therefore be considered as at least as good as in a direct-current generator with a compensating winding of normal value located in the pole faces only.

In the application of interpoles to the synchronous converter the same principles should hold as in a direct-current generator, namely, the interpole magnetomotive force should be sufficient to neutralize that of the armature winding and, in addition, should set up a small magnetic flux sufficient to overcome the self induction of the commutated coil. As the magnetomotive force the armature varies between 7 per cent and 20 per cent shown in the above figures, it is evident that perfect compensation of this cannot be obtained and that therefore only some average value can be applied. Assuming that 15 per cent will be required on the average to compensate for this, then in addition the interpole winding must carry ampere turns sufficient to set up the small magnetic field for commutation. Thus the total ampere turns on the interpole will be equal to 15 per cent of the armature direct-current ampere turns plus a small addition for setting up the useful or commutating field. In the direct-current generator, the ampere turns on the interpoles must equal the total armature ampere turns plus a corresponding addition for the commutating field. It is therefore evident that an interpole winding on a converter will naturally be very much smaller than on a direct-current generator, and in general it is between 25 per cent and 40 per cent of the direct-current.

In the pulsating resultant magnetomotive force in the converter there lies one possible source of trouble with interpoles. Assume, for example, the total ampere turns on the interpoles are equal to 30 per cent of the direct-current ampere turns on the rotary and that 15 per cent of this is for overcoming the average value of the resultant magnetomotive force, then an average of 15 per cent will be available for setting up a commutating field; but, according to the above diagrams, the resultant magnetomotive force of the armature varies from 7 per cent to 20 per cent. With a total interpole winding representing 30 per cent, then the effective or magnetizing part will vary from 30–7 to 30–20; that is, from 23 per cent to 10 per cent. The effective magnetomotive force therefore tends to vary over quite a wide range so that the commutating field would also tend to vary up or down over a very considerable range, which is an undesirable thing for commutation. However, as this pulsation is at a fairly high frequency it tends to damp itself out by setting up eddy currents in the structure of the magnetic circuit. If a good conducting damper or closed circuit were placed around the interpole, it is probable that this pulsation would be almost

completely eliminated, but such a damper possesses certain disadvantages, as will be shown later.

In practice this pulsation of the armature reaction under the interpoles is apparently not noticeably harmful in most cases, as evidenced by the fact that well-proportioned interpole converters in commercial service show no undue trouble at the commutator or brushes.

Due to the relatively small number of ampere turns required on the interpole of a converter compared with those required on a direct-current generator, the design of the interpoles in the two cases presents quite different problems. In the direct-current generator the interpoles carry ampere turns, which in all cases are greater than the armature ampere turns, as explained before. As the field ampere turns on the main poles are, not infrequently, but little greater than the armature ampere turns, it is evident that the interpole winding may, in some cases, carry as many ampere turns as the main field windings. While but a small per cent of these interpole windings is effective in producing flux under the pole tip, yet they are all effective in producing leakage from the sides of the poles. As the interpoles are generally small in section compared with the main poles, and as they may carry ampere turns equal to the main poles, it is evident that the effect of leakage may be relatively great on the interpole.

For instance, if the leakage on the main poles is 15 per cent of the useful flux, then, with the same total leakage on the interpoles, this may represent a very high value compared with the useful flux, due to the small section of the interpole and the relatively low useful interpole flux. In consequence, it is considerable of a problem to proportion the interpoles of a direct current generator so that the leakage flux will not saturate the interpoles at some part of the circuit. If they saturate, then part of the ampere turns on the interpole are expended in such saturation and the part thus expended must be counted off from the extra or excess interpole ampere turns. If, for example, the interpole winding requires 100 per cent for overcoming the armature and there is 20 per cent extra ampere turns for setting up a useful flux, then any saturation in the interpole circuit must represent additional ampere turns on the field, as the above 120 per cent is necessary for useful flux and for neutralizing the armature. With reduced current, and consequent lower saturation, these additional interpole turns become effective in mag-

netizing the gap and thus the commutating flux is too strong. At greatly increased load, more ampere turns are required for saturation, and the commutating flux is altogether too weak. It is thus evident that a machine with highly saturated interpoles will not commutate equally well for all loads. Herein lies a problem in the design of interpole generators, as it is difficult to maintain a relatively low saturation in the interpoles due to their small section and high ampere turns which cause leakage. It is well known that in the main poles of the generator, a leakage flux which is higher than the useful flux is objectionable, from the designer's standpoint; and yet in the use of interpoles this is a normal condition rather than an exception.

In the synchronous converter the conditions are somewhat different due to the fact that the interpole ampere turns are usually only 25 per cent to 40 per cent as great as on a corresponding direct-current generator. The leakage at the sides of the poles becomes relatively much less, while the useful induction remains about the same as on the direct-current generator. In consequence, saturation of the poles is not so difficult to avoid. In some cases, due to the smaller ampere turns on the interpole winding, the interpole coils can be located nearer the pole tip and thus the leakage can be further reduced. However, the placing of the interpole coil over the whole length of the pole is not as objectionable in the converter interpole as it is on the direct-current generator as the ampere turns are less. It is those ampere turns which are located close to the yoke, or furthest away from the pole tip, which produce the highest leakage, while those close to the pole tip usually produce much less leakage, but in interpole generators with their high number of ampere turns on the interpoles it is often difficult to find space for the interpole winding, even if distributed over the whole pole length. In some cases, a direct-current machine may be larger than would otherwise be required, simply to obtain space for the interpole winding. This is not true to the same extent in the application of interpoles to converters.

In the above the leakage is referred to as a function of the interpole winding as if the main winding had little or nothing to do with it. The reason for this may be given as follows:

Fig. 9 represents two main poles and an interpole of a direct-current generator or converter, with their windings in place. The direction of current or polarity of each side of each coil is also indicated by + or −. It is evident that between the inter-

pole and one main pole, the interpole winding and the main field winding are of the same polarity, while on the opposite side of the interpole, these two windings are in opposition. Let A equal the ampere turns of the interpole and B the ampere turns in the main coil. Then, $A+B$ will represent the leakage ampere turns at one side of the interpole and $A-B$ will represent the leakage ampere turns at the other side. Therefore, the leakage at the two sides of the poles is represented by $(A+B)+(A-B) = 2A$; that is, the leakage could be considered as due to the interpole winding entirely and may also be considered as due to double the interpole turns acting as one side of the interpole only. Another way of looking at this is to consider that the windings on the main pole produce leakage in the interpoles, but the leakage due to one main pole acts radially in one direction in the interpole, while that due to the other main pole is in the opposite direction.

Considering therefore the interpole leakage as being due to the interpole ampere turns only, it is evident that the synchronous converter will not be troubled with saturation of the interpoles to the same extent as a direct-current generator. With the same size of interpole it is evident that the converter should be able to carry heavier overloads than the direct-current generator before saturation of the interpoles is reached.

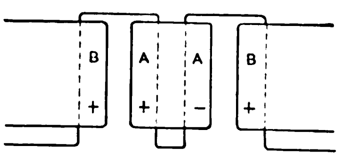


FIG. 9

It was mentioned before that a closed conducting circuit around the interpoles would be objectionable. This has been proved by experience with interpole generators. It is evident from the preceding analysis that the ampere turns on the interpole of a direct-current generator should always rise or fall in proportion to the armature ampere turns in order to give best commutation, assuming, of course, no saturation of the poles. If the interpole turns are directly in series with the armature winding, with no shunt across the interpole winding, it is evident that the interpole ampere turns must vary in direct proportion to the armature ampere turns. However, if a non-inductive shunt, for instance, were connected across the interpole winding in order to shunt part of the current, then in the event of a sudden change in load, the interpole winding being inductive due to its iron core and the shunt being non-inductive, the momentary

division of current during a change in load would not be the same as under steady conditions. In other words, if the armature and interpole current were suddenly increased, then a large part of the increase would momentarily pass through the non-inductive interpole shunt until steady conditions were again attained. In consequence, the interpole ampere turns would not increase in proportion to the armature ampere turns just at the critical time when the proper commutating field should be obtained.

The same condition is approximated when a separate conducting circuit is closed around the interpole. A sudden change in the current in the interpole winding, causes a change in the flux, and secondary currents are set up in the closed circuit, which always act in such a way as to oppose any change in the flux, whereas, the flux in reality should change directly with the current. The above described non-inductive shunt across the interpole winding might be considered also as completing a closed circuit with the interpole winding, and therefore retarding secondary currents would be set up in this closed circuit with any change in the flux in the interpole.

In some cases it may be impracticable to get exactly the right number of turns on the interpole winding to give the correct interpole magnetomotive force. For example, on a heavy current machine, 1.8 turns carrying full current might be required on each interpole. If two turns were used, with the extra current shunted, the right interpole strength would be obtained. A non-inductive shunt, however, is bad, as shown above. However, if an inductive shunt is used, instead of non-inductive, and the reactance in this shunt circuit is properly adjusted, then it is possible to get the right interpole strength for normal conditions and still obtain satisfactory conditions with sudden changes in load. Also, by arranging the interpole winding so that a very considerable percentage of the current is shunted normally by an inductive shunt having a relatively high reactance compared with the interpole, it should be possible to force an excess current through the interpole winding in case of a sudden increase in load, in case a stronger commutating field were needed at this instant.

On the interpole synchronous converter a non-inductive shunt across the interpole winding should act very much as on an interpole generator and therefore non-inductive shunts are inadvisable. If any shunting is required it should be by means of an inductive shunt in those cases where the current from the con-

verter is liable to sudden fluctuations, as in railway service. Where the service is practically steady, a non-inductive shunt should prove satisfactory for the interpoles of converters or direct-current generators.

Under extreme conditions of overload current, that is, in case of a short circuit across the terminals, it is questionable to what extent interpoles are effective. It is practicable to design interpoles on direct-current generators which will not unduly saturate up to possibly three or four times normal load. However, in case of a sudden short circuit the current delivered by the machine is liable momentarily to rise to a value anywhere from 15 to 30 times full load current. With this excessive current the interpoles of the direct-current generator must necessarily be more or less ineffective. On account of saturation, the commutating flux under the interpole cannot rise in proportion to the current. However, there should still be some commutating field present, which condition is probably considerably better than no field at all, or a strong field in the opposite direction as would be found without commutating poles. Therefore, in direct-current generators with well-proportioned interpoles, the conditions on short circuit are generally less severe than in non-interpole machines.

If the pole is highly saturated by the heavy current rush on short circuit, then it is evident that a highly inductive shunt, as described above, which would increase the interpole current in a greater proportion than the armature current, would simply mean higher saturation with little or no increase in the useful flux under the interpole.

In the synchronous converter at short circuit the conditions may be somewhat different. When the converter is short circuited it can also give extremely high currents, possibly much greater than the corresponding direct-current generator can give. Both the armature winding tied to an alternating-current supply system, and the presence of the low resistance dampers on the field magnetic circuit, tend to make the short circuit conditions more severe in the converter. The worst condition, however, would appear to be in the relation of the interpole ampere turns to the armature ampere turns on short circuit. As shown before, the normal ampere turns on the interpole winding will be only 25 per cent to 40 per cent of the direct-current ampere turns on the armature. In the case of a sudden short circuit the armature momentarily may deliver a very considerable current as a direct-

current generator, and the armature reaction, or the resultant magnetomotive force, may approach that of a direct-current generator. In such case the ampere turns on the interpole will be very much smaller than the armature resultant magnetomotive force at this instant and thus there will be no commutating flux under the interpole, but, on the contrary, the armature being stronger, there will be a reverse flux which may be considerably higher than if no interpole were present, as the iron of the interpole represents an improved magnetic path for such flux. While the converter armature will probably never deliver all its energy as a direct-current generator at the instant of short circuit, yet it may be assumed that it will deliver some of its load thus, and it does not require a very large per cent to be generator action in order to neutralize, or even reverse the effect of the interpoles. In consequence, on a short circuit the converter may have a reverse field under the commutating pole, while the direct-current generator under the same condition will have a field of the proper direction but of insufficient strength which, however, is a much better condition than a field of the wrong polarity.

The inductive shunt mentioned before, which normally shunts a considerable portion of the interpole current, might be more effective in a converter than in a direct-current generator in the case of a short circuit. In a direct-current generator, the interpoles would be so highly saturated, as described before, that the increase in current in the interpole winding due to the inductive shunt would be relatively ineffective. In the converter, however, the saturation of the interpole can normally be very much lower than in the direct-current generator and it might be practicable to so proportion these interpoles that they do not saturate highly, even on short circuit. In consequence, a strong inductive shunt might force up the interpole ampere turns so that the negative field under the interpole would be much decreased, or might even be changed to a positive field and thus become useful in commutation. This would be helpful *only during the short circuit.* However, converters not infrequently flash over or "buck" when the circuit breaker is opened on a very heavy overload or a short circuit and not when the first rush of current occurs. If the flash tends to occur at the opening of the circuit, then the above mentioned inductive shunt might have just the opposite effect from what is desired, for it would tend to develop or maintain a stronger

field under the interpole after the armature reaction is removed. In consequence, the heavy inductive shunt might prove harmful in such a case.

Another condition exists in a converter which does not exist in a generator. When a short circuit occurs on a direct-current generator, the armature reaction tends to distort the main field very greatly—so much so that the field of the machine is very greatly weakened. This decreases the terminal voltage and the resultant decrease in the shunt excitation will still further tend to weaken the field. In consequence, the machine tends to " kill " its magnetic field and the voltage tends to drop to a low value. Therefore, when the breaker opens on a short circuit the direct-current voltage may be falling rapidly. When the armature current is removed from the machine the voltage may rise slowly, depending upon the natural rate of building up the field. Consequently, after the breaker opens there is little or no tendency to flash, and practically all difficulties occur during the current rush, before the breaker opens. In a converter, however, the conditions are different. The armature of the converter is tied to an alternating-current supply system which tends to maintain the voltage on the converter. The machine cannot " kill " its field in the same way as the direct-current generator, for the alternating-current system tends to maintain the field by corrective currents which act in such a way as to tend to hold up the voltage. An enormous current may be drawn from the alternating-current system momentarily in case of a short circuit on the direct-current side of the converter. This heavy alternating current may cause a drop in the alternating-current lines, step-down transformers, etc., so that the supply voltage does fall very considerably and the direct-current voltage does drop materially in case of a short circuit. However, the instant the short circuit is removed by opening the breaker, then the converter at once tends to attain full voltage as the alternating-current supply system tends to bring the armature up quickly to normal voltage conditions. In consequence there may be a relatively heavy current flow in the alternating-current side of the machine, while there is no direct-current flow in the armature. Part of this alternating-current flow represents energy in bringing the machine back to a normal condition, and part is purely magnetizing or wattless current. The energy component tends to produce an armature magnetomotive force giving an active field at the point of commutation. This energy component alter-

nating-current flow, however, cannot be corrected by interpoles, as there is no direct current flowing.

A further difference between the synchronous converter and the direct-current generator, in case of a short circuit, lies in the results of field distortion. The enormous short circut current from the converter with the armature acting partly as a direct-current generator, may very greatly shift or distort the field flux. The dampers on the field poles tend to delay this distortion. Also, after distortion has occurred they tend to maintain the distorted or shifted field so that momentarily after the circuit breaker opens the converter may be operating without direct-current load but with a very badly distorted or shifted field. This also tends to produce sparking or flashing after the direct-current breaker has opened.

Another condition which may affect the action of interpoles on converters, but which does not occur in direct-current generators, is hunting. When hunting occurs in a converter the energy current delivered to the alternating-current side of the converter pulsates, or varies up and down over a certain range, which may be either large or small. At the same time the direct-current flow is apparently varied but little. In consequence, the resultant magnetizing effects of the alternating current and direct current do not nearly neutralize each other at all times. When the alternating-current energy input is least the converter delivers part of its direct-current load as a generator, the stored energy in the rotating armature being partly given up to supplying the direct-current power. In this case the resultant magnetomotive force may be a very considerable per cent of the maximum direct-current magnetomotive force of the armature winding. Also, the magnetic field under the main poles is distorted or shifted toward one pole edge. The armature necessarily slows down during this operation, the field polarity of all the poles being shifted toward one pole edge. The position of maximum e.m.f. of the alternating-current end and also the position of maximum alternating-current flow may be shifted to a certain extent also. In consequence, the magnetomotive force due to the alternating-current flow will be shifted circumferentially a certain amount, while the direct-current magnetomotive force cannot be shifted, being fixed in position by the brushes. In consequence, the alternating-current magnetomotive force may not be in direct opposition to the direct-current at this instant, and the resultant magnetomotive force may be

much higher than at normal condition. A moment later the swing may be in the opposite direction; that is, the alternating armature current may be greater than direct current and the energy being received from the alternating-current system is considerably greater than is given out by the direct current. Again, the two magnetomotive forces will not nearly neutralize each other and there also will be field distortion, but in the opposite direction, and again, the two magnetomotive forces will not be in direct opposition to each other circumferentially. If hunting is very severe, the resultant magnetomotive force of the armature due to the inequality of the input and output, and to the circumferential shifting of the magnetomotive forces with respect to each other, may vary enormously and may pass from positive to negative values periodically. It is evident that under such condition the presence of an interpole may give much worse results than if no interpole were present; for, as mentioned before, if there is a magnetomotive force in the wrong direction at the interpole, the interpole magnetic circuit apparently makes conditions worse. In consequence, an interpole synchronous converter should be especially well designed to avoid hunting.

All of the above considerations have taken into account only the energy currents delivered to the alternating-current side of the converter. Some consideration should be given to the effect of wattless currents in connection with interpoles.

As is well known, when a synchronous converter has its field strength improperly adjusted for the required alternating-current counter e.m.f., alternating currents will flow in the armature in such a way as to correct the effect of the improper field strength; that is, if the field is too weak wattless currents will flow in the armature which tend to magnetize the field of the converter. These currents will be leading in the armature, but will be lagging with respect to the line. On the other hand, if the converter field is too strong, these wattless or corrective currents will tend to weaken the field and will lag with respect to the armature, but will lead with respect to the line. These corrective currents will have a lead or lag of 90 deg. with respect to the energy currents. Their magnetomotive forces also will have a lead or lag of 90 deg. from the magnetomotive force of the energy component of alternating-current input. As this latter practically coincides with the direct-current magnetomotive force, which is midway between the main poles, the corrective armature currents will have a maximum magnetomotive force practically

under the middle of the main poles and therefore become purely magnetizing or demagnetizing due to such position. Also, being at right angles to the energy component, the magnetomotive forces of the corrective currents will have zero value where the energy component has maximum, and therefore should have no direct effect upon the resultant magnetomotive force midway between the main poles, or under the interpoles if such are used. It might be assumed therefore that the usual wattless or corrective currents, which the converter may carry on account of improper field strength, will have no direct harmful effect on the commutation. However, there are apparently some indirect effects due to this corrective current, for when a converter is operated at a bad power-factor, either leading or lagging, there is generally more trouble at the commutator and brushes than when a high power-factor is maintained.

Kw.	Volts	Poles	Rev. per min.	Cycles	Amperes per brush arm
3000	600	16	187	25	625
2000	250	18	167	25	889
1000	250	10	300	25	800
800	250	8	375	25	800
1000	250	14	514	60	570
500	250	10	720	60	400
1000	600	12	600	60	278
500	600	8	900	60	208
300	600	6	1200	60	167

It has been shown that the maximum possible benefit to be derived from interpoles in neutralizing armature reaction is much less in synchronous converters than in direct-current generators. In direct-current generators and motors interpoles have also been of great advantage, due to variable speed and variable voltage requirements. In synchronous converters, however, the requirement of variable speed is obviously absent and that of variable voltage very limited. The converter has constant voltage characteristics and variable voltage can only be obtained through the agency of such relatively expensive devices as induction regulators, synchronous boosters or split-pole constructions. The advantages of interpoles in synchronous converters are then to be looked for only in the direction of increased outputs and higher speeds.

It will be instructive, before considering the possibility of advance in this direction to take a brief survey of what has been accomplished without interpoles. The data of some machines of large output and high speed which have been built and placed in operation in the United States are given in the accompanying table.

The 3000-kw. converters mentioned above are the largest converters so far built. Eleven of these units have been installed or are being built for two of the traction companies of New York City. It is of interest to note that a number of these units are replacing 1500-kw. 250-rev. per min. units installed about ten years ago in the same substations, thereby doubling

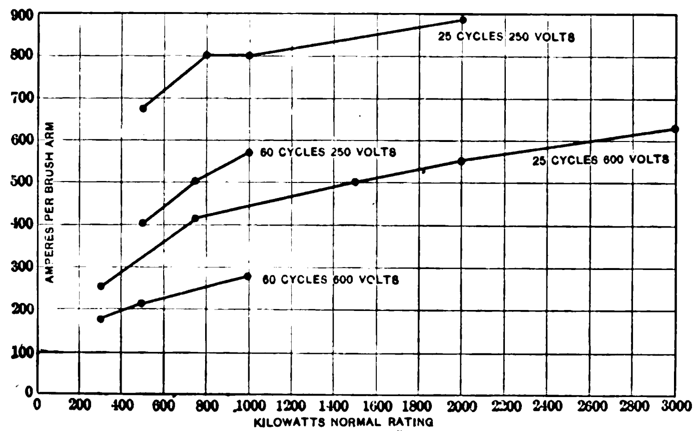


FIG. 10

the capacity of the stations without increasing the real estate investment. The speed of these 3000-kw. units is the same as that of the 2000-kw. which, when designed four and a half years ago, represented the extreme in output and speed.

The same ratings given in the table are plotted in the curve, Fig. 10, to which has been added other ratings which have been proposed and which can obviously be built in view of their relation to ratings which have been built. Fig. 10 represents concisely the situation to-day as far as the writers are familiar with it. The curves bring out very nicely the relation between permissible amperes per brush arm and frequency and voltage. It will be noted that the permissible current is greater in the 250-volt converters than in the 600-volt converters, and greater

in the 25-cycle converters than in the 60-cycle converters of the same voltage. These differences call attention to the fact, important in connection with the study of interpoles, that there are limits to speed and output other than the limit affected by interpoles—the limit of sparking.

In any commutating machine the commutating conditions are dependent, to a large extent, on the number of poles. If, in a given design the commutation design constants are unduly large, the conditions can be improved by increasing the number of poles, since this, with the " parallel " windings invariably used in larger machines, increases the number of circuits in parallel and decreases the current to be commutated in a single circuit. In a direct-current generator the number of poles can be varied with in fairly wide limits with a given speed, since the alternations of the machine are not of controlling importance. In the synchronous converters, on the contrary, the number of poles and the speed are rigidly interconnected by the frequency of the supply circuit. This imposes a limitation in converter design which is not present in the design of direct-current generators. The least number of poles which a direct-current generator can have is determined largely by the total current to be handled and to a less extent by the speed. There is a maximum current which can be handled by each brush arm or for each pair of poles; this current is determined by the permissible length of commutator which, in turn, is determined by the stresses, the type of commutator construction employed, and the skill of the available manufacturing department. Due to the fixed relation between poles and speed in rotary converters, there is a fixed relation between the frequency and the commutator peripheral speed. The peripheral speed in feet per minute is equal to the alternations per minute of the supply circuit times the distance in feet between adjacent neutral points on the commutator. With the same distance between neutral points, the peripheral speed of commutators in 60-cycle converters is necessarily 2.4 times the peripheral speed of 25-cycle commutators. This does not mean that 25- and 60-cycle converters are actually built with this difference in peripheral speed, but that 60-cycle converters are pushed as high in peripheral speed as possible while 25-cycle converters are designed with a somewhat lower peripheral speed and with a proportionately greater distance between neutral points which, in turn, determine to a marked degree the sensitiveness of the machine in operation.

Another matter which has a bearing on the speed of converters is the fact that in any machine, whether an alternating-current generator, direct-current generator, or synchronous converter, there is a limit in the number of poles below which little or no reduction in cost results in spite of the increased speed. This is best shown by the relative costs of two-pole and four-pole alternating-current turbo-generators, but is also true of other machines although to a less degree where the number of poles is greater.

With these facts in mind, the difference in the high and low voltage and high and low frequency converters can be considered.

25 Cycles, 250 Volts. Due to the low frequency, low commutator peripheral speeds are possible without exceeding very conservative limits in distance between neutral points and voltage between adjacent commutator bars. This permits very long commutators, without exceeding safe mechanical limits. The large currents due to the low voltage require at best a large number of poles, which results in a low speed in revolutions, and which also simplifies the mechanical problem of the commutator design. The large currents to be handled, particularly in the larger outputs, make it desirable to push to the limit the current per brush arm. The permissible current per brush arm is high due to the favorable conditions mentioned above and the result is seen in the high values of amperes per brush arm used in converters of this class. It is evident that for converters of low voltage and low frequency the limit to further increase in speed —with consequent decrease in poles—is *length of commutator* rather than sparking.

25 Cycles, 600 Volts. As in the 250-volt converters, low frequency permits low commutator peripheral speed which, in turn, permits relatively long commutators. The smaller currents to be handled, however, permit fewer poles which results in higher speeds than in the corresponding 250-volt converters which necessitates somewhat shorter commutators. The result is that, due to the higher speeds, the limit in amperes per brush arm is lower than in the 250-volt converters. By comparing the curves for 25-cycle 600-volts, and 60-cycle 250 volts in Fig. 10 it is evident that somewhat higher values of amperes per brush arm could be used for the former, since for the same kilowatts and speed the amperes per brush arm are equal. Either the highest available speed has not been employed in existing de-

signs, or higher speeds could be used if interpoles were added. With these converters the limits to further increase in speed is not the length of the commutator.

60 Cycles, 250 Volts. The maximum possible speed at the commutator is used in order to increase the space between neutral points, and the number of poles are chosen as small as possible without exceeding questionable operative speeds. This imposes very severe mechanical conditions in the commutator design. Going as far in this direction as is represented by the ratings mentioned above, the number of poles is still larger than would be selected in a direct-current generator of the same rating. The amperes per brush arm are smaller than in the 25-cycle converters of the same voltage due to the larger number of poles imposed by the frequency requirement.

We question, however, whether higher speeds and greater amperes per brush arm are possible without radically changing the present type of commutator construction. Here, then, as in the low-frequency, low-voltage converters, the barrier to higher speeds is found in the commutator mechanical design rather than in the electrical design.

60 Cycles, 600 Volts. As in the 250-volt, 60-cycle converters, the number of poles is made as small as possible, keeping within permissible speeds, but, with the small currents handled in 600-volt converters and the larger number of poles necessitated by the high frequency, the amperes per brush arm as shown by Fig. 10 are very low.

The limit to higher speed is obviously not amperes per brush arm. Interpoles would probably permit higher speeds due to more favorable sparking conditions, but higher speeds than those now used would certainly require changes in present commutator designs.

The higher speeds now used by the large American manufacturers of synchronous converters were introduced within a very recent date for units above 300 kw. With the relatively low commutator peripheral speeds previously used, the distance between brush arms was very small. This restricted the design to a comparatively small number of commutator bars between neutral points with a high voltage between bars, particularly in 600-volt converters. The use of a large number of poles resulted in very narrow neutral spaces between poles so that, with the combined effects of narrow neutral and high "volts per bar," 600-volt, 60-cycle converters had a bad reputation for

sensitiveness to wrong brush position and to "bucking", when compared with the substantial characteristics of low frequency converters. The later apparently radical increase in speeds has placed 60-cycle converters in the same class with the majority of 25-cycle machines now on the market in those features of design tending toward stability in operation. If this increase in speed which has been successfully accomplished without interpoles, had proven unsuccessful, due to commutation difficulties, then interpoles would without any question be justified for 60-cycle converters.

To summarize the above discussion of the various limits to increased speed: It would appear that 25-cycle, 600-volt converters offer the most promising field for the application of interpoles; that 60-cycle, 600-volt converters follow next and that 60-cycle and 25-cycle 250-volt converters show the least possibilities of improvement from the standpoint of design.

If the use of interpoles permits higher speeds and outputs than those possible without interpoles from the standpoint of commutation it will be necessary to raise our present limits imposed by the construction of commutators except possibly in 25-cycle railway converters, if advantage is to be taken of the higher speeds. These limits may be raised materially only by a change in the type of commutator construction used. In all of the converters referred to the usual *V*-ring commutator is employed. The shrink-ring construction developed for direct current turbo-generators might be used, especially for lower voltages, and the limits in peripheral speed and length of commutator be considerably extended. It may be found, however, that the use of this type would necessitate commutators of small diameter compared with those now used in synchronous converters, in order to obtain a construction of sufficient rigidity. This would in turn necessitate the use of the number of poles and speeds approaching those used in direct-current turbo-generators in order to obtain the necessary output. Such extreme proportions would apparently result in more expensive machines than those of the proportions now used without interpoles. A serious objection to the use of shrink-ring commutators is the difficulty of making repairs on them after installation. This, in general, limits the use of shrink-ring commutators to machines in which other constructions simply cannot be employed. Commutator dimensions and speeds comparable with turbo-generator practice would only be possible with 60-cycle apparatus. As a matter of

fact it is not a long step from our present 60-cycle converter speeds to those usual in direct-current turbo-generators in this country. In the 300-kw., 600-volt, 60-cycle converter referred to, any further increase in speed would necessarily be from the present six poles to a four-pole converter operating at 1800 rev. per min. This is the same as the speed selected for a number of direct-current turbo-generators of 300-kw. capacity. Similarly, the 500-kw., eight-pole, 900-rev. per min. converter, if changed, would be a six-pole 1200-rev. per min. converter which is not very different from 1500 rev. per min. selected by several manufacturers for the direct-current turbo-generator of 500-kw. capacity.

The question of satisfactory commutator design for high speeds is a question that concerns the man who has to construct the commutator and the man who has to operate it, equally with the man who designs it. A large high-speed commutator is, whatever the design, a wonderful contrivance requiring constructive ability of the highest order and, when completed and put in operation, requiring careful attention on the part of the operator. Defects unnoticed at low speeds become disastrous at high speeds. The type of construction and the limits in size and speed are not to be changed without very careful consideration.

Granting that increased speeds are feasible through the use of interpoles, and that it is possible to build satisfactory commutators at the increased speeds and increased current outputs, the question still remains whether such a change results in a sufficient reduction in cost or improvement in performance to warrant the change. Considering 25-cycle, 600-volt converters, it is without question possible to build a 300-rev. per min. 1500-kw. converter without interpoles of a design in line with conservative practice. There is ample basis for the belief that still without interpoles, the speed could be increased to 375 rev. per min. without sacrificing good commutating limits, and that, with interpoles, and, assuming that a satisfactory commutator could be designed and built, the speed could be further increased to 500 rev. per min. But, comparing the material required in the eight-pole 375-rev. per min. converter and in the six-pole 500-rev. per min. converter, it will probably be found that the cost of the six-pole machine of such large capacity is as great as or greater than the eight-pole. It is also questionable whether the 750-kw. size which is now built with six poles for 500 rev. per min. could be changed to four poles and 750 rev. per min. with a decrease in cost sufficient to warrant the change.

As an illustration of what high speeds and long commutators will lead to, Fig. 11 is shown. This is a 25-cycle, eight-pole, 375-rev. per min. 800-kw. 250-volt, 3200-ampere synchronous converter. This machine carries a synchronous booster between the collector rings and the rear end of the armature, but this adds but little to the dimensions of the machine. The great length of the machine, compared with its diameter, should be noted. The use of interpoles would probably not allow any material change in the dimensions of this machine.

Considering 60-cycle converters, both 600- and 250-volt, any increase in speed would result in machines comparable with direct-current turbo-generators in type of construction and in cost. To state the matter conservatively, it is extremely doubtful whether any material increase in speeds above those now known to be possible without interpoles can be made with enough saving in cost to compensate for the expense of adding interpole windings, if such are required.

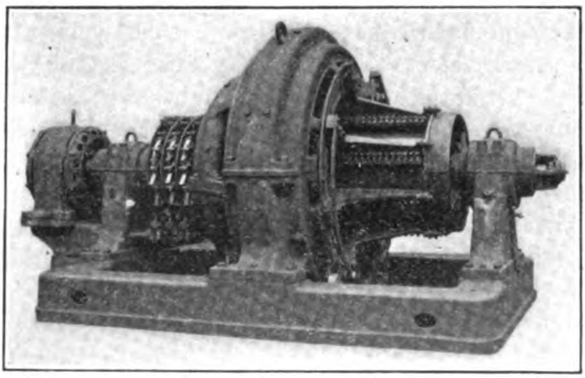


FIG. 11

The actual construction of converters with interpoles would be attended by some minor disadvantages. The field structure would be considerably complicated by the additional field winding, particularly in the case of converters for three-wire service in which both the series and interpole field windings would have to be connected in both the positive and negative circuits. In all cases the addition of the interpole would considerably crowd the field structure and increase the temperature rises in the converter unless it were designed with greater diameter to pro-

vide sufficient space for the interpoles without crowding. The efficiency of an interpole machine would in general be slightly lower than that of the corresponding machine without interpoles, due to the addition of the interpole losses. In the event of the use of higher speeds, the efficiencies will be considerably lowered by the increased friction loss due to the bearings, brushes and windage, unless the reduction in iron and copper losses is sufficient to compensate for the increased friction.

The advantages and disadvantages chargeable to interpoles may be summarized as follows:

1. Assuming that considerably higher speeds could be used:

Advantages.

a. Possible reduction in cost.

b. Less attention required in operation.

c. Longer life of commutator and brushes.

The advantages *b* and *c* may be more than counterbalanced under the present assumption, by the greater difficulty of maintaining any commutator in proper condition with the higher speed assumed.

Disadvantages.

a. Possibility of increased trouble from bucking on sudden changes in load or short circuits.

b. Possible reduction in efficiencies, particularly in light load.

c. Higher operating temperatures unless the same temperatures as now obtained in non-interpole machines are maintained by partly sacrificing the advantage of lower cost.

2. On the assumption that no higher speeds will be used with interpoles than have been found to be practicable without interpoles, but that the interpoles will be added simply as a refinement to machines that would operate satisfactorily without them.

Advantages.

a. Less attention required during operation.

b. Longer life of commutator and brushes.

Disadvantages.

a. Possibility of increased trouble from bucking on sudden changes in load or short circuits.

b. Slightly lower efficiencies.

c. Higher operating temperatures.

d. Greater cost due to the addition of interpoles.

This is true of course only with the stated assumption that the converter is designed to operate satisfactorily without interpoles. It would probably be possible to design a converter with interpoles without exceeding the cost of the non-interpole machine as has been done in other types of apparatus, but this would be done by making a machine which is unsatisfactory without interpoles and then improving the commutating conditions by interpoles. Such result, however, would hardly represent an improvement over present practice.

In conclusion, the authors have attempted to state the case for and against interpoles in all fairness. From the standpoint of design it seems difficult to make a sufficiently strong case for the interpole in synchronous converters to warrant the additional complication in construction. At best the addition of interpoles, properly applied, represents a refinement over present designs, and the fundamental question is whether such refinement is justified commercially. This question, however, must be decided, as all engineering problems are finally decided, not by the judgment of one man or any group of men, but by the results of experience in extended operation.

A paper to be presented at the 254th meeting of the American Institute of Electrical Engineers, New York, December 9, 1910.

(*Subject to final revision for the Transactions.*)

TESTING STEAM TURBINES AND STEAM TURBO-GENERATORS*

BY E. D. DICKINSON AND L. T. ROBINSON

Of late years an increasing amount of consideration is being given to the economic production of power, and as the cost of coal in a steam power station is the largest item of expense, it naturally follows that the efficiency of the apparatus for generating power should be high. In order to determine these efficiencies, certain accurate measurements, or tests, are necessary, and it is the intention to outline what precautions must be taken, in order that the results may not be misleading, and also to consider the relative degrees of accuracy of different methods.

The term efficiency is a fruitful source of misunderstanding. The only meaning which is of any commercial significance to the operating engineer is that which gives the ratio between the energy in the form he desires, to the energy available in the fuel. In other words, what he wants to know is, how much is he getting out for what he puts in.

There is one point that must at all times be kept in mind and that is, that all tests, even when accurate, are at best but an indication of what may be expected in the over-all economy of the station. A specific example of this is a certain European power house, which contained several engines of the best makes. When steam turbines were installed, the coal consumption was decreased about 20 per cent, though the test efficiency of the turbines showed no such marked superiority over that of the engines.

In the manufacturing of steam turbines a great amount of testing is necessary, to determine the effect of making changes in design or to verify theories and formulæ which cannot be

*This paper is to be presented at the New York meeting of the A.I.E.E., December 9, 1910. Notice of oral discussion or any written discussion should be mailed to reach the Secretary before date of meeting. Written contributions received within 30 days thereafter will be treated as if presented at the meeting.

established by calculation; much of this is of an experimental or laboratory nature. There is also a large amount of testing done, in order to establish the over-all economy of the complete unit. This latter is all that is of commercial value to those operating steam turbines. The actual efficiency of the turbine alone, is of some interest, but can only be determined by measuring the power delivered by the shaft to some form of brake, or to a generator of known efficiency. Any testing by allowing for the different losses, by the methods often employed for electrical apparatus is impractical and should not be considered.

In this paper it is not the intention to elaborate all the numerous details which must be carefully taken care of when tests are being made. Many points of importance are only touched upon. Every test must be given special consideration, and the necessary precautions to be taken will depend on local conditions.

Measurement of the Steam Input

Weighing Condensed Steam. The one positive method of testing a turbo-generator is to measure the steam that goes in through the throttle valve, and the electric energy delivered at the terminals of the generator. The surest method of determining how much steam enters the turbine is to collect and weigh all the steam after it has been condensed. This necessitates the use of a condenser of the surface type. In making such a test two things are essential: First that all the steam used on the turbine be condensed and measured; and second, that no steam or water, not used in the turbine, be allowed to enter the condenser. Should the condenser not be perfectly tight, some of the cooling water will be drawn into the condenser, and mixed with the condensed steam; this is a common source of error. The condenser should have leakage checked, before and after each test. With all steam turned off the turbine the condenser should be run for some time with full vacuum, and the discharge from the hot well pump very accurately measured.

Split condenser tubes will sometimes cause leakage which is extremely difficult to locate, and cannot always be determined by measuring the leakage. This is the case when the split opens up only when the condenser is heated with large flows of steam. This action will generally give erratic results, and no tests should be considered that do not show consistency with other tests on the same machine.

Measuring Condensed Steam. The most accurate method

of measuring the condensed steam is by the use of tanks, so arranged that all the water can be weighed at equal time intervals during the test. The pump, piping and tanks must be free from leaks, and the condenser and pumps must be so arranged that the water will continuously flow to the pump, this is essential in order to get accurate results.

Weighing Water Fed to Boilers. This method is quite frequently resorted to when the condensed steam cannot be measured, as is the case when the turbine is operating non-condensing, or when the condenser is of the jet type, in which the cooling water is mixed with condensed steam. In making such tests, the liability to error is very great, and every precaution must be taken in order that the results may be considered reliable within any degree of accuracy.

The steam piping connecting the boilers and turbine must be disconnected from all other piping, and all openings must be blanked off; valves must not be relied on. All blow off and drain valves must have their outlets visible. All piping between boiler feed-pumps and boilers must be exposed, and have no branches. Leakage of the boiler itself is the most difficult to locate, as all water or steam escaping is vaporized and carried up the stack. The boiler leakage should be checked before and after each test by closing the throttle to the turbine, or if necessary blanking the pipes at the turbine and running a test measuring the amount of water required with full steam pressure on boilers and piping. The feed water used should be weighed, and not measured by meters.

Tests which have come under our observation have shown boiler leakage of 10 and 12 per cent of the water weighed into the boilers, and one particular case showed a leakage of over 20 per cent.

Test by Heat Balance. This method of testing is based on measuring the amount of heat transferred to the cooling water from the condensed steam. It is extremely inaccurate and unreliable, and at best can give but an approximate idea of the quantity of steam being condensed. The quantity and temperature of cooling water and the temperature of the outgoing water, carrying with it the condensed steam, are measured as accurately as possible. The reason for inaccuracies is the difficulty of measuring the quantity of cooling water and its true average temperature change. The temperature of the cooling water may vary at different sides of the pipe, and small discrepancies in the

reading will show large variations in the estimated steam consumption of the turbine, since the temperature rise is small.

Duration of Tests. In order to establish accurately any given point, all tests should be run with fixed conditions after a state of equilibrium is established and things are constant for an appreciable length of time. The time required will depend on the nature of the test being made. In general, when small amounts are being measured, the duration of the tests should be somewhat greater, for example, when measuring the condenser leakage, this test should be run for a sufficiently long period in order that the small quantity of water which will come through may be accurately weighed.

Efficiencies. The net over-all efficiency expressed by the ratio between the kilowatt hours output of the generator, and the available energy in the steam, is the only one of any particular commercial value. The comparison of efficiencies of different machines is the most satisfactory way of considering their relative merits. To determine the available energy in one pound of steam it is necessary to know the pressure in pounds per square inch, the quality and the temperature of the entering steam; also the pressure at the turbine exhaust. To measure the exhaust pressure, or vacuum, a gauge should not be relied on. The most accurate means is to use a full length mercury gauge, and subtract the readings given by this, from the atmospheric pressure at the time the test is made. If the steam be superheated, since there is some difference of opinion concerning the specific heat of superheated steam, the figure assumed must be given.

In testing turbines consisting of several stages, the pressures in the different stages should be measured, this affords a check, and should show any abnormal conditions existing in the interior, which might not otherwise be observed.

The kilowatt output should be net, that is, the kilowatts for excitation should be subtracted from the generator output.

Checking Instruments. All instruments, including meters, gauges, thermometers, and scales must be very accurately calibrated or checked before and after the test. Small inaccuracies in some of the readings may entirely discredit tests which have cost a great deal of money to make.

Inspection and Adjustment. Before tests are made the turbine should be inspected to see that all parts are in proper condition. If necessary the interior should be examined to see that the

buckets have not been damaged by foreign substances, and all necessary adjustments made at this time. After the tests have been completed, the machine should be ready for commercial service, and no adjustments of the turbine should be made.

Corrections. Whenever possible, turbines should be tested under the conditions for which they were built to operate. Correcting for different conditions is always liable to throw some doubt upon the accuracy of the test, and therefore on the efficiency of the machine being tested. Different machines will have different correction factors for varying conditions, and for this reason it is impossible to arbitrarily fix the allowances that should be made.

In general, the corrections for steam pressure, moisture, or superheat, are less liable to be misleading than that for varying vacuum, for the reason that comparatively large changes in any one of the first three, will but slightly affect the conditions in the machine; whereas, a slight change in the vacuum makes an enormous change in the available energy and volume of the steam in the low pressure end of the turbine. A turbine may show a splendid efficiency with poor vacuum, but unless it be properly proportioned, it may give a poor efficiency with a good vacuum.

Test Results. The majority of commercial tests on turbogenerators are made to determine whether or not the unit is fulfilling the guarantees made by the manufacturer of the apparatus. The steam turbine differs from the reciprocating steam engine, in that it is impossible to take any readings that will give a direct indication of the power being developed. The designing engineer with all necessary data, can estimate very accurately what power the turbine is developing under any given set of conditions. But the operating engineer has not the time, nor is he interested in making such calculations.

It will be apparent from the foregoing, that the complete test of a unit, necessitates taking a large number of measurements, and small inaccuracies in taking many of the readings are liable to affect considerably the final results. For this reason, it is obvious that no machine should be discredited on account of small variation in the final results.

With the high efficiencies now being obtained, small inaccuracies in readings will show a relatively large per cent variation in the steam consumption. It is for this reason that manufacturers guarantee an efficiency which is not quite so good as

may be expected from the unit. Another method is to guarantee the efficiency that may be expected, with an allowance to cover permissible inaccuracies in making tests.

The Steam Flow Meter. Under suitable circumstances, thoroughly accurate tests may be made by measuring the steam with a meter. Such tests will be more convenient than those made by any other method. Certain precautions are necessary, but there should be small expense in providing conditions that will insure reliable results with the best meters.

Even where other methods of measurement are used the steam flow meter will always be a valuable adjunct since its readings are accurately proportionate to flow and show the conditions instantaneously.

Measuring the Electrical Output in Connection with Turbine Tests

The output of the turbo-generator may be either direct current or alternating current. We will consider first the measurement of direct-current output. Usually, station instruments in connection with generator switchboard have been provided, but unless temperature conditions can be very accurately controlled and the instruments can be checked under operating conditions they should not be used. The station voltmeters may sometimes be satisfactory but it is the usual practice to supply direct current station ammeters to operate from shunts of approximately 60 millivolts drop which requires that the indicating part of the ammeter be largely a copper circuit; therefore the whole combination is subject to considerable error due to variations in room temperature, and with some shunt arrangements, to variations in the current to be measured as well. For the precise measurement of direct-current output, portable indicating ammeters should be used having 200-millivolt-drop shunts,* and, therefore, permitting the use of indicating millivoltmeters whose circuit consists largely of resistance material having practically no temperature coefficient. It is also desirable, when possible, to measure the volts by similar portable voltmeters.

When using either switchboard or portable instruments the influence of any stray fields should be investigated and arrangements made whereby these stray fields will not affect the mea-

* This is not an arbitrary value but has been chosen by several makers as giving the best compensation of all temperature errors.

sured output. Special caution must be observed in this respect if the instruments are not of a shielded type. If the influence of stray fields is very small it may be eliminated from the final result by periodically turning the instruments between successive readings. There is also another point in connection with the measurement of amperes, especially when testing large units, which is important, namely, care should be taken to correct the observed indications of the millivoltmeter for any electromotive forces that may appear in the shunt or leads due to thermo-electric effects. The amount of error due to this cause may be observed by reading the millivoltmeter at the close of the test with no current flowing in the main circuit. There may then be observed a small positive or negative indication, which should be applied as a correction to the observed ampere readings. Of course, to have this correction constant throughout the test the entire arrangement should be run under the test load until final temperature conditions in the shunt have been established. These precautions need not be observed in connection with standard precision shunts having 200 millivolts drop.

Referring again to the station type of shunts, unless the ammeter is checked with the shunt connected into the bus bars, great care should be taken to know that the distribution of current flow throug h the shunt is the same when the ammeter is used, as when it was tested. It is quite possible to have large errors due to this cause.

Measurement of Alternating-current Output. If the output is small—less than 20 or 30 kw.—wattmeters, ammeters and voltmeters without current or volt-multipliers may be used. The same remarks with regard to disturbing influences, which apply with direct current instruments apply with even greater force to instruments for alternating current. They are not usually much affected by steady magnetic fields but in many locations where large generators must be tested there may be fields which would have an appreciable effect on the indications of the instruments and which would alternate with the same frequency as the circuit to be tested. The current leads of the circuit under test may become a source of error. Such fields require the use of shielded instruments or the careful handling of those of the unshielded sort to eliminate any possible errors.

After all questions in connection with the instruments themselves have been disposed of it is necessary to consider the proper use of the instrument transformers which provide usually the

only means of enlarging the capacity of the instruments to meet ordinary requirements.

The station equipment provided for use with the generator can be checked carefully and both the instruments and transformers employed for the precision test, but this is not usually as convenient as to insert transformers specially tested for the work. Of course, if the constructors of the plant have the foresight to install tested transformers these are, at any time available, for precision testing. Makers of instrument transformers can supply them with certificates showing performance under any specified conditions when requested.

In using instrument transformers it is necessary to observe the precaution to have the secondary connected load the same as that which is on the transformers when they were tested for the certificate. It is also necessary if the test is to be made under conditions that will give low power-factor on circuits to at least know that the phase displacements in the instrument transformers are not large enough to appreciably affect the results. It is also well to observe the precaution not to use instrument transformers with interconnected secondaries except for the common ground connection which should be employed as a safety precaution.

If possible, a test should be made on non-inductive load. If this is done the indications of the voltmeters, and ammeters, may be used to check the indications of the wattmeters. If all the test arrangements have been satisfactorily attended to the apparent power as showed by the volts and amperes should agree within one per cent with the wattmeter indications and the watts indicated should be taken as the true output. If the test cannot be made at unity power-factor, the voltmeters and ammeters should still be included so that the general conditions of distribution of load etc., may be known throughout the test. For this purpose the station instruments would be satisfactory.

The use of watthour meters for this class of testing should be avoided wherever possible. There are watthour meters for direct-current and for alternating-current circuits, and under both of these headings there are those which might be classed as accurate and those which could hardly be so described. Still the very best watthour meters that can be made are inferior in performance to the best portable indicating instruments. Watthour meters are slightly affected by changes of voltage, frequency, wave shape, etc., and by the amount of load current

which is being measured. Sometimes if the load is very fluctuating and the test must be made under service conditions the output may be more accurately determined by watthour meters than by indicating instruments, but this would represent extreme conditions, and would not usually be true.

Watthour meters should never be used unless checked in place at the frequency, voltage, wave shape, etc., which are to be used in testing. If it is not possible to run a complete test on a fairly steady load it is usually possible to make a few runs on the watthour meter under load conditions and to use this check as a basis for determining the output by means of the watthour meters during the test run on unsteady load. It is still advisable to read the indicating instruments at short intervals so that their indications may be made use of in computing the final result. The fluctuations shown by the recorded values will determine how much weight should be given to the indicating instruments.

Checks of watthour meters should not, for precision purposes, be made with the meter subjected to other than exact load conditions and on the same circuit. Compromise methods of testing watthour meters, similar to the usual test of a three-phase two-element meter on a single-phase circuit, should not be used.* This is because the accuracy demanded is better than that in ordinary metering and does not mean that the compromise test is not perfectly satisfactory for ordinary service for meters known to be without interference between elements. If watthour meters are tested in place, using the above precautions, and indicating instruments are employed and read at frequent intervals during a test run of three to five hours, the watthour record should agree with the output as determined by the indicating instruments within one per cent on fairly steady commercial loads with the chances largely in favor of the indicating instruments being correct. Single-phase indicating instruments for polyphase service are to be preferred for precision work to polyphase instruments, for the obvious reason that indications of a polyphase instrument are made up by the two elements in such a way that it is not possible to apply corrections to either element to get the true total result unless the division of load is known by single phase instruments; and if the single phase instruments are required for this purpose they may as well be of the precision class and used for the actual determinations, and the polyphase instrument omitted.

* Meter Code VII, J. 88, I and II.

Conclusion

To accurately and positively determine the efficiency of a steam turbine, great care must be taken in making the tests. If all necessary precautions are not taken, the results are liable to be misleading, and will in all probability be absolutely valueless so far as determining the actual economy of the unit.

The modern steam turbine, unlike the reciprocating engine, should require no adjustments before making economy tests, that is, after it has been adjusted, any turbine should be able to stand all the sudden variations of load and steam conditions occurring in commercial operation. The turbine should be tested with the adjustments that are normally maintained. After tests have been made to establish the economy of a turbine, no adjustments should be made, that may affect the efficiency. Any such adjustments may discredit the entire test.

The testing of steam turbines in some respects resembles the testing of water turbines, and it is recognized what precautions have to be taken in testing them in order to avoid misleading results. The testing of steam turbines demands even more care, owing to the greater number of conditions which have to be maintained and accurately measured.

With the ever increasing search for higher economies in the production of power, the efficiency of every piece of apparatus that forms a link in the chain between the coal pile and the switchboard must be maintained at its best, and in a turbine power station it is not sufficient to know the efficiency of the turbine alone, but every source of loss should be run down and eliminated or reduced to its minimum. Several small losses may in the aggregate be sufficient to cause an otherwise economical plant to make a very poor showing.

A paper to be presented at the Pittsfield-Schenectady mid-year convention of the American Institute of Electrical Engineers, February, 1911.

MECHANICAL FORCES IN MAGNETIC FIELDS*

BY CHARLES P. STEINMETZ

1. General

Mechanical forces appear wherever magnetic fields act on electric currents. The work done by all electric motors is the result of these forces. In electric generators, they oppose the driving power and thereby consume the power which finds its equivalent in the electric power output. The motions produced by the electromagnet are due to these forces. Between the primary and the secondary coils of the transformer, between conductor and return conductor of an electric circuit, etc., such mechanical forces appear.

The electromagnet, and all electrodynamic machinery, are based on the use of these mechanical forces between electric conductors and magnetic fields. So also is that type of transformer which transforms constant alternating voltage into constant alternating current. In most other cases however, these mechanical forces are not used, and therefore are commonly neglected in the design of the apparatus, under the assumption that the construction used to withstand the ordinary mechanical strains to which the apparatus may be exposed, is sufficiently strong to withstand the magnetic mechanical forces. In the large apparatus, operating in the modern huge electric generating systems, these mechanical forces due to magnetic fields may however, especially under abnormal, though not infrequently occurring conditions of operation (as short circuits), assume such formidable values, so far beyond the normal mechanical strains, as to require consideration. Thus large transformers on big generating systems have been torn to pieces by

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the magnetic mechanical forces of short circuits, cables have been torn from their supports, disconnecting switches blown open, etc.

In the following, a general study of these forces will be given. This also gives a more rational and thereby more accurate design of the electromagnet, and permits the determination of what may be called the efficiency of an electromagnet.

Investigations and calculations dealing with one form of energy only, as electromagnetic energy, or mechanical energy, usually are relatively simple and can be carried out with very high accuracy. Difficulties however arise when the calculation involves the relation between several different forms of energy, as electric energy and mechanical energy. While the elementary relations between different forms of energy are relatively simple, the calculation involving a transformation from one form of energy to another, usually becomes so complex, that it either can not be carried out at all, or even only approximate calculation becomes rather laborious and at the same time gives only a low degree of accuracy. In most calculations involving the transformation between different forms of energy, therefore it is preferable not to consider the relations between the different forms of energy at all, but to use the *law of conservation of energy* to relate the different forms of energy, which are involved.

Thus, when mechanical motions are produced by the action of a magnetic field on an electric circuit, energy is consumed in the electric circuit, by an induced e.m.f. At the same time, the stored magnetic energy of the system may change. By the law of conservation of energy, we have

Electric energy consumed by the induced e.m.f. = mechanical energy produced, + increase of the stored magnetic energy. (1)

The consumed electric energy, and the stored magnetic energy, are easily calculated, as their calculation involves one form of energy only, and this calculation then gives the mechanical work done, $= F\,l$, where F = mechanical force, and l = distance over which this force moves.

Where mechanical work is not required, but merely the mechanical forces, which exist, as where the system is supported against motions by the mechanical forces—as primary and secondary coils of a transformer, or cable and return cable of a circuit—the same method of calculation can be employed, by assuming some distance l of the motion (or dl); calculating the

mechanical energy $w_0 = F\,l$ by (**1**), and therefrom the mechanical force as $F = \frac{w_0}{l}$, or $F = \frac{d w_0}{d l}$.

Since the induced e.m.f., which consumes (or produces) the electric energy, and also the stored magnetic energy, depend on the current and the inductance of the electric circuit, and in alternating-current circuits the impressed voltage also depends on the inductance of the circuit, the inductance can frequently be expressed by supply voltage and current; and by substituting this in equation (**1**), the mechanical work of the magnetic forces can thus be expressed, in alternating-current apparatus, by supply voltage and current.

In this manner, it becomes possible for instance to express the mechanical work and thereby the pull of an alternating electromagnet, by simple expressions of voltage and current, or to give the mechanical strains occurring in a transformer under short circuits, by an expression containing only the terminal voltage, the short-circuit current, and the distance between primary and secondary coils, without entering into the details of the construction of the apparatus.

This general method, based on the law of conservation of energy, will be illustrated by some examples, and the general equations then given.

2. The Constant Current Electromagnet

Such magnets are, for instance, the series operating magnets of constant current arc lamps on direct-current and alternating-current circuits.

Let i_0 = current, which is constant during the motion of the armature of the electromagnet, from its initial position 1, to its final position 2, l = the length of this motion, or the stroke of the electromagnet, in cm., and n = number of turns of the magnet winding.

The magnetic flux ϕ, and the inductance

$$L = \frac{n\,\phi}{i_0}\,10^{-8} \qquad (2)$$

of the magnet, vary during the motion of its armature, from a minimum value,

$$\phi_1 = \frac{i_0\,L_1}{n}\,10^{8} \qquad (3)$$

in the initial position, to a maximum value,

$$\phi_2 = \frac{i_0 \, L_2}{n} \, 10^8 \tag{4}$$

in the end position of the armature.

Hereby an e.m.f. is induced in the magnet winding,

$$e' = n \, \frac{d \, \phi}{d \, t} \, 10^{-8} = i_0 \, \frac{d \, L}{d \, t} \tag{5}$$

This consumes the power

$$p = i_0 \, e' = i_0^2 \, \frac{d \, L}{d \, t} \tag{6}$$

and thereby the energy

$$w = \int_1^2 p \, d \, t = n \, i_0^2 \, (L_2 - L_1) \tag{7}$$

Assuming that the inductance, in any fixed position of the armature, does not vary with the current, that is, that magnetic saturation is absent,* the stored magnetic energy is:

In the initial position, 1,

$$w_1 = \frac{i_0^2 \, L_1}{2} \tag{8}$$

in the end position, 2,

$$w_2 = \frac{i_0^2 \, L_2}{2} \tag{9}$$

The increase of the stored magnetic energy, during the motion of the armature, thus is

$$w' = w_2 - w_1 = \frac{i_0^2}{2} \, (L_2 - L_1) \tag{10}$$

* If magnetic saturation is reached, the stored magnetic energy is taken from the magnetization curve, as the area between this curve and the vertical axis.

The mechanical work done by the electromagnet thus is, by the law of conservation of energy,

$$w_0 = w - w'$$

$$= \frac{i_0^2}{2} (L_2 - L_1) \text{ joules.} \tag{11}$$

If l = length of stroke, in cm., F = average force, or pull of the magnet, in grammes weight, the mechanical work is

$$F\,l \text{ g-cm.}$$

Since

$$g = 981 \text{ cm-sec.} \tag{12}$$

= acceleration of gravity, the mechanical work is, in absolute units,

$$F\,l\,g$$

and since one joule = 10^7 absolute units, the mechanical work is

$$w_0 = F\,l\,g\,10^{+7} \text{ joules.} \tag{13}$$

From **(11)** and **(12)** then follows:

$$F\,l = \frac{i_0^2}{2\,g} (L_2 - L_1)\,10^{+7} \text{ g-cm.} \tag{14}$$

as the *mechanical work of the electromagnet*, and:

$$F = \frac{i_0^2}{2\,g} \frac{L_2 - L_1}{l} 10^7 \text{ g.} \tag{15}$$

as the average force, or pull of the electromagnet, during its stroke l.

Or, if we consider only a motion element $d\,l$;

$$F = \frac{i_0^2}{2\,g} \frac{d\,L}{d\,l} 10^{+7} \text{ g.} \tag{16}$$

as the force, or pull of the electromagnet in any position l.

Reducing from g-cm. to ft-lb., that is, giving the stroke l in feet, the pull F in pounds, we divide by

$$454 \times 30.5 = 13{,}850$$

which gives, after substituting for g from (**12**):

$$(\mathbf{14}): \; F\,l = 3.68\, i_0^2\, (L_2 - L_1) \text{ ft.-lb.} \tag{17}$$

$$(\mathbf{15}): \; F = 3.68\, i_0^2\, \frac{L_2 - L_1}{l} \text{ lb.} \tag{18}$$

$$(\mathbf{16}): \; F = 3.68\, i_0^2\, \frac{d\,L}{d\,l} \text{ lb.} \tag{19}$$

These equations apply to the direct-current electromagnet as well as to the alternating-current electromagnet.

In the alternating-current electromagnet, if i_0 is the effective value of the current, F is the effective or average value of the pull, and the pull or force of the electromagnet pulsates with double frequency between 0 and 2 F.

In the alternating-current electromagnet usually the voltage consumed by the resistance of the winding, $i_0\, r$, can be neglected compared with the voltage consumed by the reactance of the winding, $i_0\, x$, and the latter, therefore, is practically equal to the terminal voltage e of the electromagnet. We have then, by the general equation of self-induction,

$$e = 2\,\pi\, f\, L\, i_0 \tag{20}$$

where f = frequency, in cycles per second.

From which follows,

$$i_0\, L = \frac{e}{2\,\pi\, f} \tag{21}$$

and substituting (**21**) in equations (**14**) to (**19**), gives as the equation of the *mechanical work, and the pull of the alternating-current electromagnet.*

In the metric system;

$$F\,l = \frac{i_0\,(e_2 - e_1)\,10^7}{4\,\pi\, f\, g} \text{ g-cm.} \tag{22}$$

$$F = \frac{i_0\,(e_2 - e_1)\,10^7}{4\,\pi\, f\, g\, l} = \frac{i_0}{4\,\pi\, f\, g}\,\frac{d\,e}{d\,l}\,10^7 \text{ g.} \tag{23}$$

In foot pounds;

$$F\,l = \frac{.586\; i_0\,(e_2 - e_1)}{f} \text{ ft-lb.} \tag{24}$$

$$F = \frac{.586\; i_0\,(e_2 - e_1)}{f\,l} = \frac{.586 i_0}{f} \;\frac{d\,e}{d\,l} \text{ lb.} \tag{25}$$

Example.—In a 60-cycle alternating-current lamp magnet, the stroke is 3 cm., the voltage, consumed at the constant alternating current of 3 amperes is 8 volts in the initial position, 17 volts in the end position. What is the average pull of the magnet?

$$l = 3 \text{ cm.}$$

$$e_1 = 8$$

$$e_2 = 17$$

$$f = 60$$

$$i_0 = 3$$

Hence, by (**23**):

$$F = 367 \text{ g. } (= 0.81 \text{ lb.})$$

The work done by an electromagnet, and thus its pull, depend, by equation (**22**), on the current i_0 and the difference in voltage between the initial and the end position of the armature, $e_2 - e_1$; that is, depend upon the difference in the volt-amperes consumed by the electromagnet at the beginning and at the end of the stroke. With a given maximum volt-amperes, $i_0\,e_2$, available for the electromagnet, the maximum work would thus be done, that is, the greatest pull produced, if the volt-amperes at the beginning of the stroke were zero, that is, $e_1 = 0$, and the theoretical maximum output of the magnet thus would be

$$F_m\,l = \frac{i_0\,e_2\,10^7}{4\,\pi\,f\,g} \tag{26}$$

and the ratio of the actual output, to the theoretically maximum

output, or the efficiency of the electromagnet, thus is, by (**22**) and (**26**),

$$\eta = \frac{F}{F_m} = \frac{e_2 - e_1}{e_2} \tag{27}$$

or, using the more general equation (**14**), which also applies to the direct current electromagnet;

$$\eta = \frac{L_2 - L_1}{L_2} \tag{28}$$

The efficiency of the electromagnet, therefore, is the difference between maximum and minimum voltage, divided by the maximum voltage; or the difference between maximum and minimum volt-ampere consumption, divided by the maximum volt-ampere consumption; or the difference between maximum and minimum inductance, divided by the maximum inductance.

As seen, this expression of efficiency is of the same form as that of the thermodynamic engine;

$$\frac{T_2 - T_1}{T_2}$$

From (**26**) it also follows, that the maximum work which can be derived from a given expenditure of volt-amperes, $i_0\, e_2$, is limited. For $i_0\, e_2 = 1$, that is, for one volt-ampere, the maximum work, which could be derived from an alternating electromagnet, is, from (**26**):

$$F_m\, l = \frac{10^7}{4\,\pi f g} = \frac{8100}{f} \text{ g-cm.} \tag{29}$$

That is, a 60-cycle electromagnet can never give more than 135 g-cm., and a 25-cycle electromagnet never more than 324 g-cm. pull per volt-ampere supplied to its terminals.

Or inversely, for an average pull of one g. over a distance of one cm., a minimum of $\frac{1}{135}$ volt-ampere is required at 60 cycles, and a minimum of $\frac{1}{324}$ volt-ampere at 25 cycles.

Or, reduced to pounds and inches:

For an average pull of one lb. over a distance of one in., at least 8.6 volt-amperes are required at 60 cycles, and at least 3.6 volt-amperes at 25 cycles.

This gives a criterion by which to judge the success of the design of electromagnets.

3. The Constant Potential Alternating Electromagnet

If a constant alternating potential e_0 is impressed upon an electromagnet, and the voltage consumed by the resistance, $i\,r$, can be neglected, the voltage consumed by the reactance x is constant and is the terminal voltage e_0, thus the magnetic flux ϕ also is constant during the motion of the armature of the electromagnet. The current i however varies, and decreases from a maximum i_1 in the initial position, to a minimum i_2 in the end position of the armature, while the inductance increases from L_1 to L_2.

The voltage induced in the electric circuit by the motion of the armature,

$$e' = n \frac{d\,\phi}{d\,t} 10^{-8} \tag{30}$$

then is zero, and therefore also the electrical energy expended;

$$w = 0$$

That is, the electric circuit does no work, but the mechanical work of moving the armature is done by the stored magnetic energy.

The increase of the stored magnetic energy is

$$w' = \frac{i_2^2 L_2 - i_1^2 L_1}{2} \tag{31}$$

and since the mechanical energy, in joules, is by (**13**),

$$w_0 = F\,l\,g\,10^{-7}$$

the equation of the law of conservation of energy,

$$w = w' + w_0 \tag{32}$$

then becomes

$$0 = \frac{i_2^2 L_2 - i_1^2 L_1}{2} + F l g \, 10^{-7}$$

or

$$F l = \frac{i_1^2 L_1 - i_2^2 L_2}{2 g} 10^7 \text{ g-cm.} \tag{33}$$

Since, from the equation of self-induction, in the initial position;

$$e_0 = 2 \pi f L_1 i_1 \tag{34}$$

in the end position;

$$e_0 = 2 \pi f L_2 i_2 \tag{35}$$

substituting (**34**) and (**35**) in (**33**), gives the equation of the constant potential alternating electromagnet.

$$F l = \frac{e_0 (i_1 - i_2)}{4 \pi f g} 10^7 \text{ g-cm.} \tag{36}$$

and

$$F = \frac{e_0 (i_1 - i_2)}{4 \pi f g l} 10^7 = \frac{e_0}{4 \pi f g} \frac{d i}{d l} 10^7 \text{ g.} \tag{37}$$

or, in ft-lb.

$$F l = \frac{.586 \, e_0 (i_1 - i_2)}{f} \text{ ft-lb.} \tag{38}$$

$$F = \frac{.586 \, e_0 (i_1 - i_2)}{f l} = \frac{.586 \, e_0}{f} \frac{d i}{d l} \text{ lb.} \tag{39}$$

Substituting $Q = e i$ = volt-amperes, in equations (**36**) to (**39**) of the constant potential alternating electromagnet, and equations (**22**) to (**25**) of the constant-current alternating magnet, gives the same expression of mechanical work and pull:

In metric system,

$$F\,l = \frac{\Delta\,Q}{4\,\pi\,f\,g}\,10^7 \text{ g-cm.} \tag{40}$$

$$F = \frac{\Delta\,Q}{4\,\pi\,f\,g\,l}\,10^7 = \frac{1}{4\,\pi\,f\,g}\,\frac{d\,Q}{d\,l}\,10^7 \text{ g.} \tag{41}$$

In foot-pounds,

$$F\,l = \frac{.586\;\Delta\,Q}{f} \text{ ft-lb.} \tag{42}$$

$$F = \frac{.586\;\Delta\,Q}{f\,l} = \frac{.586}{f}\,\frac{d\,Q}{d\,l} \text{ lb.} \tag{43}$$

where $\Delta\,Q$ = difference in volt-amperes consumed by the magnet in the initial position, and in the end position of the armature.

Both types of alternating current magnet then give the same expression of efficiency;

$$\eta = \frac{\Delta\,Q}{Q_m} \tag{44}$$

where Q_m is the maximum volt-amperes consumed, corresponding to the end position in the constant current magnet, to the initial position in the constant potential magnet.

4. Short Circuit Stresses in Alternating Current Transformers

At short circuit, no magnetic flux passes through the secondary coils of the transformer, if we neglect the small voltage consumed by the ohmic resistance of the secondary coils. If the supply system is sufficiently large to maintain constant voltage at the primary terminals of the transformer even at short circuit, full magnetic flux passes through the primary coils.* In this case the total magnetic flux passes between

* If the terminal voltage drops at short circuit on the transformer secondaries, the magnetic flux through the transformer primaries drops in the same proportion, and the mechanical forces in the transformer drop with the square of the primary terminal voltage, and with a great drop of the terminal voltage, as occurs for instance with large transformers at the end of a transmission line or long feeders, the mechanical forces may drop to a small fraction of the value, which they have on a system of practically unlimited power.

primary coils and secondary coils, as self-inductive or leakage flux. If then x = self-inductive or leakage reactance, e_0 = impressed e.m.f., $i_0 = \frac{e_0}{x}$ is the short circuit current of the transformer. Or, if as usual the reactance is given in per cent, that is, the $i x$ (where i = full load current of the transformer) given in per cent of e, the short circuit current is equal to the full load current divided by the percentage reactance. Thus a transformer with 4 per cent reactance would give a short circuit current, at maintained supply voltage, of 25 times full load current.

To calculate the force F, exerted by this magnetic leakage flux on the transformer coils — (which is repulsion, since primary and secondary currents flow in opposite direction) we may assume, at constant short-circuit current i_0, the secondary coils moved against this force F, and until their magnetic centers coincide with those of the primary coils; that is, by the distance l, as shown diagrammatically in Fig. 1, the section of a shell type transformer. When brought to coincidence, no magnetic flux passes between primary and secondary coils, and during this motion, of length l, the primary coils thus have cut the total magnetic flux ϕ of the transformer.

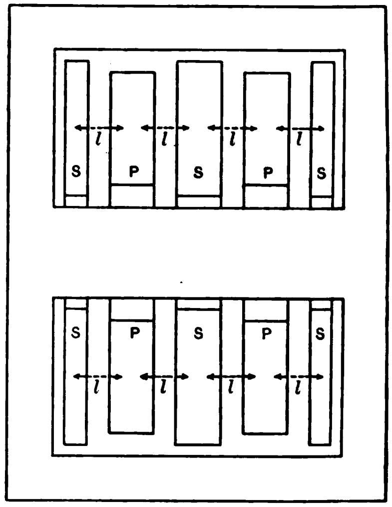

FIG. 1

Hereby in the primary coils a voltage has been induced,

$$e' = n \frac{d\,\phi}{d\,t} 10^{-8}$$

where n = effective number of primary turns.

The work done or rather absorbed by this voltage e', at current i_0, is

$$w = \int e'\, i_0\, d\,t = n\, i_0\, \phi\, 10^{-8} \text{ joules.} \qquad (45)$$

If L = leakage inductance of the transformer, at short circuit, where the entire flux ϕ is leakage flux, we have,

$$\phi = \frac{L\, i_0}{n}\, 10^8 \tag{46}$$

hence, substituted in (**45**)

$$w = i_0^2\, L \tag{47}$$

The stored magnetic energy at short circuit is

$$w_1 = \frac{i_0^2\, L}{2} \tag{48}$$

and since at the end of the assumed motion through distance l, the leakage flux has vanished by coincidence between primary and secondary coils, its stored magnetic energy also has vanished, and the change of stored magnetic energy therefore is

$$w' = w_1 = \frac{i_0^2\, L}{2} \tag{49}$$

Hence the mechanical work of the magnetic forces of the short circuit current is

$$w_0 = w - w' = \frac{i_0^2\, L}{2} \tag{50}$$

It is, however, if F is the force, in g., l the distance between the magnetic centers of primary and secondary coils:

$$w_0 = F\, l\, g\, 10^{-7} \text{ joules.}$$

Hence

$$F\, l = \frac{i_0^2\, L}{2\, g}\, 10^7 \text{ g-cm.} \tag{51}$$

and

$$F = \frac{i_0^2\, L}{2\, g\, l}\, 10^7 \text{ g.} \tag{52}$$

the mechanical force existing between primary and secondary coils of a transformer at the short circuit current i_0.

Since at short circuit, the total supply voltage e_0 is consumed by the leakage inductance of the transformer, we have

$$e_0 = 2 \pi f L i_0 \tag{53}$$

hence, substituting (**53**) in (**52**), gives

$$F = \frac{e_0 i_0 10^7}{4 \pi f g l} \text{ g.}$$

$$= \frac{8100 e_0 i_0}{f l} \text{ g.} \tag{54}$$

Example.—Let, in a 25-cycle 1667-kw. transformer, the supply voltage $e_0 = 5200$, the reactance = 4 per cent. The transformer contains two primary coils between three secondary coils, and the distance between the magnetic centers of the adjacent coils or half coils is 12 cm., as shown diagrammatically in Fig. 1. What force is exerted on each coil-face during short circuit, in a system which is so large as to maintain constant terminal voltage?

At 5200 volts and 1667 kw., the full load current is 320 amperes. At 4 per cent reactance the short-circuit current therefore $i_0 = \frac{320}{.04} = 8000$ amperes. Equation (**54**) then gives, for $f = 25$, $l = 12$;

$$F = 1120 \times 10^6 \text{ g.}$$

$$= 1120 \text{ tons.}$$

This force is exerted between the four faces of the two primary coils, and the corresponding faces of the secondary coils, and on every coil face thus is exerted the force

$$\frac{F}{4} = 280 \text{ tons.}$$

This is the average force, and the force varies with double frequency, between 0 and 560 tons, and is thus an enormous force.

Substituting $i_0 = \frac{e_0}{x}$ in (**54**), gives as the short-circuit force of an alternating current transformer, at maintained terminal voltage e_0, the value

$$F = \frac{e_0^2\, 10^7}{4\, \pi\, f\, g\, l} = \frac{8100\; e_0^2}{f\, l}\ \text{g}.$$

That is, the short circuit stresses are inversely proportional to the leakage reactance of the transformer.

In large transformers on systems of very large power, safety therefore requires the use of as high reactance as possible.

5. Repulsion between Conductor and Return Conductor

If i_0 is the current flowing in a circuit consisting of a conductor and the return conductor parallel thereto, and l the distance between the conductors, the two conductors repel each other by the mechanical force exerted by the magnetic field of the circuit, on the current in the conductor.

As this case corresponds to that considered in section 2, equation (**16**) applies, that is;

$$F = \frac{i_0^2}{2\, g}\, \frac{d\, L}{d\, l}\, 10^7\ \text{g}. \tag{16}$$

The inductance of two parallel conductors, at distance l from each other, and conductor diameter l_d, is, per cm. length of conductor;

$$L = \left(4 \log \frac{2\, l}{l_d} + \mu\right) 10^{-9}\ \text{h}. \tag{55}$$

Hence, differentiated;

$$\frac{d\, L}{d\, l} = \frac{4 \times 10^{-9}}{l}$$

and, substituted in (**16**);

$$F = \frac{i_0^2}{50\, g\, l}\ \text{g}. \tag{56}$$

or substituting **(12)**;

$$F = \frac{20.4\, i_0^2\, 10^{6}}{l} \text{ g.} \tag{57}$$

If $l = 150$ cm. (5 ft.)

$$i_0 = 200 \text{ amperes.}$$

this gives

$F = 0.0054$ g. per cm. length of circuit, hence it is inappreciable.

If however the conductors are close together, and the current very large, as the momentary short circuit current of a large alternator, the forces may become appreciable.

For example, a 2200-volt 4000-kw. quarter-phase alternator feeds through single conductor cables having a distance of 15 cm. (6 in.) from each other. A short circuit occurs in the cables, and the momentary short-circuit current is 12 times full-load current. What is the repulsion between the cables?

Full load current is, per phase, 910 amperes. Hence, short-circuit current, $i_0 = 12 \times 910 = 10{,}900$ amperes. $l = 15$. Hence,

$$F = 160 \text{ g. per cm.}$$

Or, multiplied by $\dfrac{30.5}{454}$

$$F = 10.8 \text{ lb. per ft. of cable.}$$

That is, pulsating between 0 and 21.6 lb. per ft. of cable. Hence sufficient to lift the cable from its supports and throw it aside.

In the same manner, similar problems, as the opening of disconnecting switches under short circuit, etc., can be investigated.

6. General Equations of Mechanical Forces in Magnetic Fields

In general, in an electromagnetic system in which mechanical motions occur, the inductance L is a function of the position l during the motion. If the system contains magnetic material, in general the inductance L also is a function of the current i, especially if saturation is reached in the magnetic material.

Let, then, L = inductance, as function of current i and position l.

L_1 = inductance, as function of the current i, in the initial position 1 of the system.

L_2 = inductance, as function of the current i, in the end position 2 of the system.

If then ϕ = magnetic flux, n = number of turns interlinked with the flux, the induced e.m.f. is

$$e' = n \frac{d\,\phi}{d\,t} 10^{8} \tag{58}$$

We have, however,

$$n\,\phi = i\,L\,10^{8}$$

hence,

$$e' = \frac{d\,(i\,L)}{d\,t} \tag{59}$$

the power of this induced e.m.f. is

$$p = i\,e' = i\,\frac{d\,(i\,L)}{d\,t}$$

and the energy

$$w = \int_1^2 p\;d\;t = \int_1^2 i\,d\,(\,i\,L)$$

$$= \int_1^2 i^2\;d\;L + \int_1^2 i\,L\,d\,i \tag{60}$$

The stored magnetic energy in the initial position 1 is

$$w_1 = \int_0^1 i\,d\,(i\,L_1) \tag{61}$$

In the end position 2,

$$w_2 = \int_0^2 i\,d\,(i\,L_2) \tag{62}$$

and the mechanical work thus is, by the law of conservation of energy

$$w_0 = w - w_2 + w_1$$

$$= \int_1^2 i\ d\ (i\,L) + \int_0^1 i\ d\ (i\,L_1) - \int_0^2 i\,d\,(i\,L_2) \qquad \textbf{(63)}$$

and since the mechanical work is

$$w_0 = F\,l\,g\,10^{-7} \qquad \textbf{(64)}$$

We have;

$$F\,l = \frac{10^7}{g}\left\{\int_1^2 i\,d\,(i\,L) + \int_0^1 i\,d\,(i\,L_1) - \int_0^2 i\,d\,(i\,L_2)\right\} \text{g-cm.} \qquad \textbf{(65)}$$

If L is not a function of the current i, but only of the position, that is, if saturation is absent, L_1 and L_2 are constant, and equation **(65)** becomes,

$$F\,l = \frac{10^7}{g}\left\{\int_1^2 i\,d\,(i\,L) + \frac{i_1^2\,L_1 - i_2^2\,L_2}{2}\right\} \text{g-cm.} \qquad \textbf{(66)}$$

a. If i = constant, equation **(66)** becomes:

$$F\,l = \frac{10^7}{g}\ \frac{i^2\,(L_2 - L_1)}{2}$$

(Constant-current electromagnet)

b. If L = constant, equation **(66)** becomes:

$$F\,l = 0.$$

That is, mechanical forces are exerted only where the inductance of the circuit changes with the mechanical motion which would be produced by these forces.

c. If $i L =$ constant, equation (**66**) becomes:

$$F l = \frac{10^7}{g} \cdot \frac{i L (i_1 - i_2)}{2}$$

(Constant-potential electromagnet.)

In the general case, the evaluation of equation (**66**) can usually be made graphically, from the two curves, which give the variation of L_1 with i in the initial position, of L_2 with i in the final position, and the curve giving the variation of L and i with the motion from the initial to the final position.

In alternating magnetic systems, these three curves can be determined experimentally by measuring the volts as function of the amperes, in the fixed initial and end position, and by measuring volts and amperes, as function of the intermediary positions, that is, by strictly electrical measurement.

As seen, however, the problem is not entirely determined by the two end positions, but the function by which i and L are related to each other in the intermediate positions, must also be given. That is, in the general case, the mechanical work and thus the average mechanical force, are not determined by the end positions of the electromagnetic system. This again shows an analogy to thermodynamic relations.

A paper to be presented at the Pittsfield-Schenectady mid-year convention of the American Institute of Electrical Engineers, February, 1911.

(*Subject to final revision for the Transactions.*)

PROBLEMS IN THE OPERATION OF TRANSFORMERS*

BY F. C. GREEN

The slightest puncture of a transformer means that it must be dismounted entirely before repairs can be made. The oil must be drawn out, the leads disconnected, and the structure moved to a location where there are facilities for hoisting. Moreover, there is interruption of service with consequent loss of revenue and impairment of prestige. At its best, transformer repairing in a station does not inspire a feeling of enthusiasm for the electrical arts. And yet the damaged coils with their slime are the starting point of progress along manufacturing lines, as well as of progress along those lines that lead to the consideration of electric stress, line oscillations, temperature gradient, and other similarly advanced features of the science.

Thus, the main problems in the operation of transformers are to select those best designed to meet the service requirements and to give them such care in their installation and such attention in service as will minimize liability of unnatural weakness or abnormal strains. Important problems arise in the adaptation of transformers to a variety of service.

INSTALLING

The high voltages used now make necessary a large amount of solid insulation between high-tension and low-tension coils and between coils and laminations. The present manufacturing practice calls for solid insulating materials that are fibrous. These cannot be so treated that they will not absorb at least a small amount of moisture from the air during shipment or storage. Occasionally, facilities for handling transformers at the station

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where they are to be installed admit of shipping with the oil in them, but as a rule the transformers and oil must be shipped separately. Hence the necessity for drying arises.

The full effect of the process used should extend to the fibrous insulating materials as well as to the coils. In fact, a coil has to withstand normally a voltage not exceeding 6000 or 7000 volts and usually the voltage is much lower than this, while the voltage between windings may reach a normal value of 100,000 volts in modern transmission systems. Furthermore, coils are more easily dried than the insulation between windings. The usual short-circuit run heats the coils but the effect does not extend through the heavy insulating shields, because the heat is carried up by the air circulating through the spaces between the coils and shields, and is given up to the cover and tank. The circuation of large quantities of heated air is an easy and effective process of drying. Where the tank is suitably constructed, the vacuum process of treating the transformers filled with oil, may be used. In this case the heat must be so applied as to maintain a uniform temperature of oil throughout the tank, and the degree of temperature and of vacuum must be so related as to cause the moisture to vaporize. Unevenness of temperature makes ineffective the vacuum process of drying without oil in the tank.

Oil may be dried by blowing heated air through it or by holding it at a temperature that will vaporize moisture, either at atmospheric or a lower pressure, such as is obtained in the vacuum process. The adaptation of the filter press with blotting paper to the treatment of oil, has proved to be most satisfactory. There is no danger of injury from excessive temperature, and both the moisture and sediment are removed. In case it should be found desirable, oil may be treated by means of the filter press without taking transformers out of service.

Causes of Failures

If a high-voltage transformer is built with a safety factor of ten instead of the usual factor of two, it avails nothing in case of neglect to properly install it, assuming it to have become moist in shipment. It is equally true that this same transformer, being properly installed, is about as likely to break down as the one with the safety factor or two. This brings up a consideration of the parts of the transformer most exposed to effects of conditions that practice has shown to be dangerous. Abnormal

voltage conditions are responsible for almost all transformer failures. Examination of the damaged portions has shown that it is not the total abnormal voltage impressed that is dangerous, but that the disturbance of the voltage equilibrium within the windings is responsible for a large majority of the operating troubles attributable to transformers. Thus, the percentage of puncture between high-tension and low-tension windings, or between the windings and laminations, is negligible as compared with the percentage of punctures between turns, or between portions of the same winding.

The standard practice for the potential test of high-voltage transformers is to apply twice the rated high-tension voltage between the high-tension winding and the low-tension connected to the iron. The induced voltage test is the application of twice the rated voltage to one of the windings. The purpose of the induced voltage test is to determine whether the various portions of a given winding are properly insulated from one another. This test of course subjects adjacent turns to twice the normal voltage between turns, but, as will be seen, this does not mean much except in cases of mechanical defects, which are rare.

Assume that a 100,000-volt transformer for transmission service has a normal turn voltage of 60 volts. The value of the test voltage between the high-tension winding and other parts, is 200,000 volts. To break down the transformer under this test would require, say, between 220,000 volts and 250,000 volts. Under the induced voltage test, the voltage between turns is 120 volts. But the voltage required to puncture the insulation between turns, is found to be around 5000 volts. Nevertheless, as previously pointed out, almost all failures of transformers of this kind occur between turns. Thus in the operation of transformers it is found that the designer must attempt to meet the difficult problem of taking care of a voltage between turns that may range from 60 volts under normal conditions to 5000 volts and above under abnormal conditions of line disturbances, that may not appreciably increase the line voltage, but that affect the equilibrium of the voltage within the winding to the extent of concentrating a very excessive potential across a small percentage of the total turns.

While modern lightning arresters successfully limit to a safe value the voltage between phases, and between the line and the ground, they are not adapted to the protection of the trans-

former against the concentration of a dangerous voltage upon a small percentage of the total winding.

The portions of the winding most liable to excessive voltages of this kind are towards the line ends; but this is not always the case, the relative location of the danger portion depending upon the nature of the disturbance of the voltage equilibrium. However, the percentage of transformer failures is small; but there is reason to believe that it can be reduced to an inappreciable value by means of increasing the effective insulation between parts of the winding most liable to damage, and by means of reducing line disturbances to a practicable minimum. Also, the transformer is less liable to the effects of line disturbances where its capacity in microfarads is small.

Another cause of destruction of transformers is their connection to bus bars of generators having a total capacity many times greater than that of the transformer. Before this kind of trouble appeared, with the concentration of large amounts of power, it was desired and specified that the transformer regulation should be a minimum. To meet this specification a low reactance was necessary. Thus in many instances the impedance voltage was limited to from 2 to 4 per cent. If a transformer is assumed to have 3 per cent impedance voltage, and to be backed with sufficient generator capacity to maintain normal voltage, a current about 30 times normal will flow when a feeder leading from the transformer becomes short circuited. The flow of such a current in a medium or a large size transformer produces electromagnetic stresses of many tons. The forces exerted are in such relation to one another as not only to flare the ends of coils over the supports for holding them together; but also to twist and distort the individual coils.

This sort of trouble has been cured by inserting separate reactance in circuit with transformers having low inherent reactance, by designing for higher inherent reactance, and by increasing the surfaces of coil supporting strips. Experience has shown that a quick-opening switch is not effective in protecting a transformer against the distorting forces of heavy current rushes in cases of short circuited lines.

Care in Operating

Where artificial cooling is used, the circulation of the cooling medium should not be neglected; the transformer cannot run

continuously even under no load with the circulation shut off. The cooling coil of a water-cooled transformer is liable to become stopped up with weeds and grass, which restrict the flow of water, or a coating of dirt and mud may form inside the coils, decreasing the effectiveness of the cooling. Occasionally chemical action takes place between the water and the metal of the coil resulting in a formation that lessens the effective cross section. Systematic observation of the flow and temperature of the water and of the temperature of the oil in the transformer, will give an indication of approaching danger from any of these sources.

Another feature of cooling that sometimes leads to a critical condition is the forcing of the circulation on occasions of heavy overload. If a very large amount of cold water is forced through the coil, and the coil is in good condition as regards its internal surface, then the temperature of the oil is maintained at a value, under a very heavy overload, that gives no indication of the temperature of the transformer windings. It has been demonstrated in service that it is possible to seriously overheat the windings without unduly raising the temperature of the oil.

The oil transformer that relies upon tank surface or its equivalent, for cooling, is generally considered as requiring no thought in its housing, or attention in service. It is supposed to be self-cooling, regardless of surroundings that do not admit of the free escape of the heat.

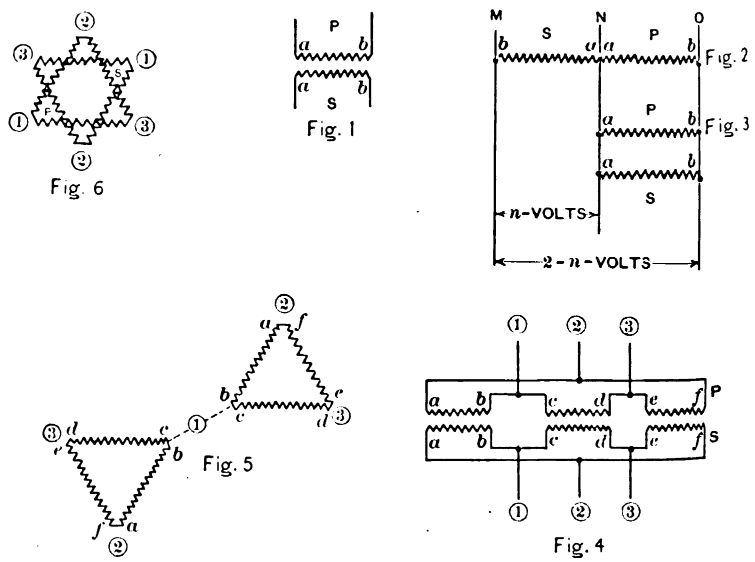
If six 500 kilovolt-ampere transformers are found operating in a room 15 ft. by 30 ft. by 15 ft. (4.6m. by 9.1m. by 4.6m.) it is generally expected that they will operate satisfactorily regardless of whether or not there are openings in the room for the circulation of air. Now assuming the losses to be 2 per cent, there are 60 kw. of energy to be radiated. This is equivalent to 80 h.p. Imagine an 80-h.p. boiler making steam at its normal rate, for a room of the dimensions given above, on a hot summer day; this will give an idea of the necessity of proper ventilation of the room and of the spacing of the transformers. To limit the temperature rise of the air in the room to 5 deg. cent., would require the circulation of approximately 21,000 cu. ft. (594 cu. m.) of air per minute. The air in the room would have to be entirely renewed three times per minute.

It should not be assumed that the manufacturer is free of responsibility in questions affecting the operation of transformers. It is not only necessary to have reliability and effi-

ciency, but the transformer case should be built so as to facilitate crude handling as well as crane handling; and connectors for changing ratio should be easy of access and manipulation.

Connections

Frequent occasion arises for the determination of the effect of a certain combination of transformers. It is an easy matter for the operator to determine whether a combination is correct or not, by simply applying the voltage; but in case the test



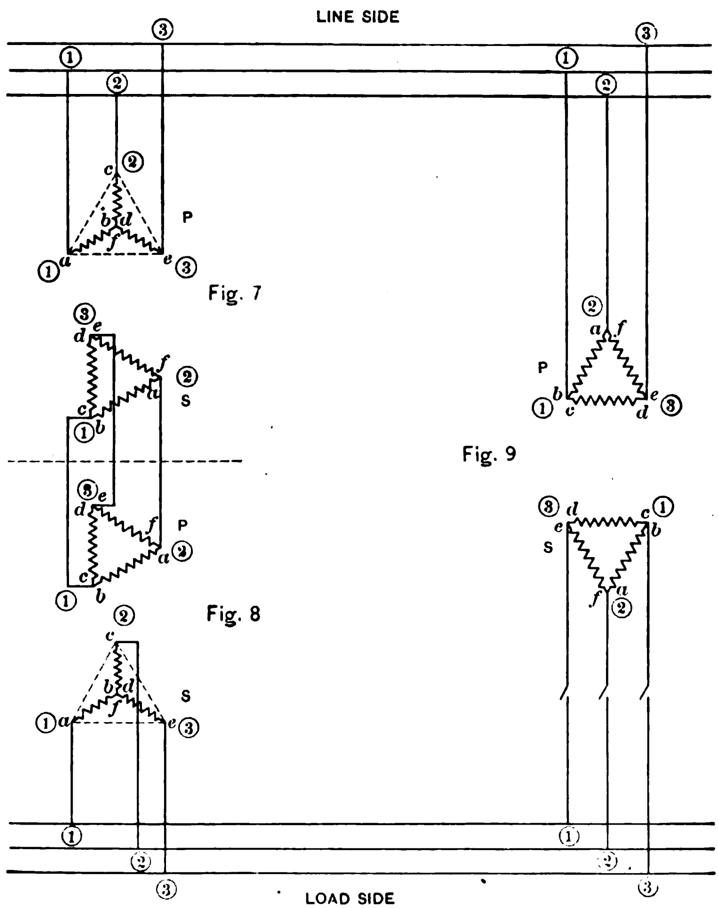
Sketch A

should prove it to be wrong, it is not always easy to figure out what the correct combination is.

The following treatment of this question is based upon instances that have arisen in connection with systems in various parts of the country. Experience has shown that there are two main divisions of this question; combinations that show their effect immediately on being energized, and combinations that do not show their effect immediately on going into service, but develop objectionable and dangerous effects under peculiar conditions.

We will take up some instances illustrating the first mentioned

division. Sketch B shows a combination that was desired to be used. The "line side" represents the high-tension or transmission side of the transformers, and the "load side" represents the low-tension or distributing side. It is not necessary to name the voltages that apply in this instance.



SKETCH B

A three-phase problem of this kind embodies phase rotation and phase position. For simplicity, we will begin with a single-phase combination shown in Sketch C, similar to the three-phase combination shown in Sketch B. There is this difference between the three-phase and single-phase combination: the single-phase combination will always have the same phase rota-

tion if the phase position is the same, while the three-phase combination may have the same phase rotation but a different phase position.

Referring to Sketch A, Fig. 1 represents a single-phase transformer with two primary leads and two secondary leads brought out of the transformer relatively as shown. Assume for simplicity that the ratio is 1:1. *M*, *N* and *O* are three wires with voltage values as indicated. Having in mind that the ratio is 1:1, whether the *a* points of the primary and secondary can be connected together and the *b* points together, without causing a short circuit, depends upon polarity; or in other words, upon whether, beginning with the *b* points, the windings follow the same direction around the core or opposite directions. If they extend in opposite directions, Fig. 2 shows the relation. *a b* of the secondary being wound opposite, lies 180 deg. from *a b* of the primary. Thus, by connecting the *a* points there is a voltage of 2 *n* volts between the *b* points.

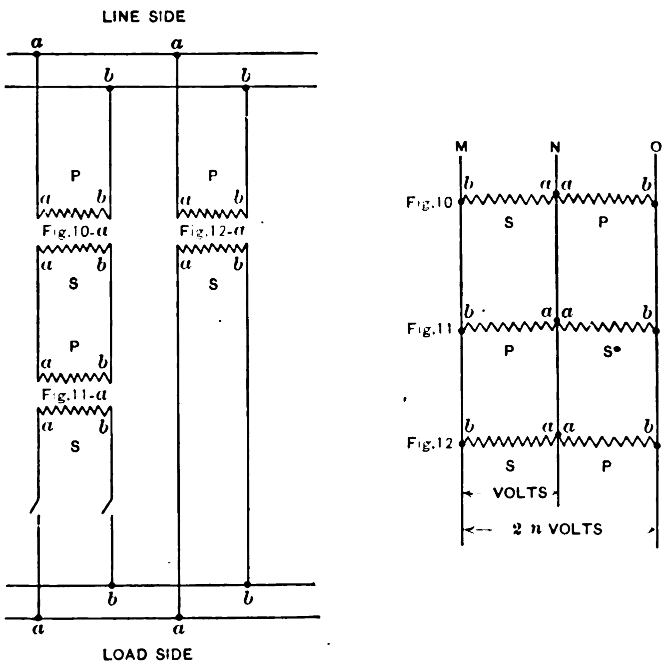
If the two windings lead from the *b* points in the same direction around the core, Fig. 3 shows the relation. Thus, there is 0 voltage between the *a* points and between the *b* points, having *n* volts between *a* and *b*. This means that the *a* points can be connected together and the *b* points together without causing a short circuit.

Referring now to Sketch *C*, and assuming that the single-phase transformers shown have primary and secondary wound in opposite directions around the core, it is found that the *a* points cannot be connected together and the *b* points cannot be connected together, as shown in Figs. 11-*a* and 12-*a*, without causing a short circuit. All that is necessary in this single-phase instance is to cross the leads of any one of the windings of any one of the transformers shown. This crossing of course would be done outside of the tank. Thus, *a* of the secondary, Fig. 11, may be connected to *b* of the secondary, Fig. 12, and *b* to *a* for the multiple connection.

If it is assumed that the polarity is such that the windings extend in the same direction around the core, then the combination of transformers as shown in Sketch C would be feasible. Furthermore, it would be feasible with any number of transformers in one of the multiple circuits as compared with the number in the other circuit.

Most transformers have primary and secondary windings leading in opposite directions around the core. The combination

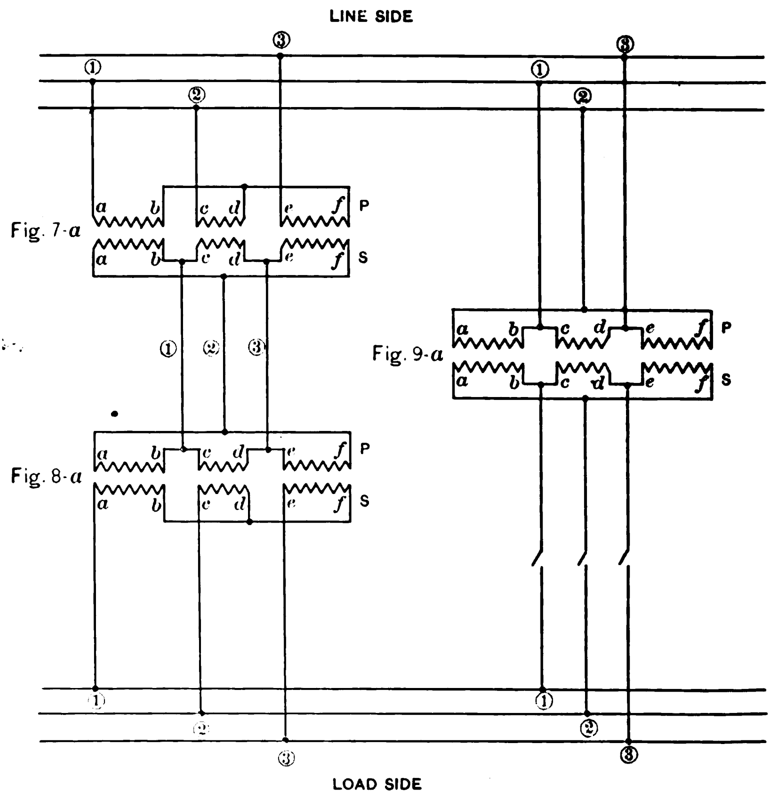
referred to in Sketch B contemplated the use of single-phase units with windings in opposite directions. It is seen in Figs. 4, 5 and 6 Sketch A that in a three-phase combination of transformers, the fact that the phase rotation is the same does not mean that the phase position is the same. Assuming a given three-phase line voltage impressed on the points 1, 2 and 3 of the primary, Fig. 4, there results the phase relation shown in Fig. 6 between the primary delta and the secondary delta. In other words, with transformers whose primary and secondary windings



SKETCH C

lead in opposite directions around the core, connected delta to delta, the primary delta makes a six-phase relation with the secondary delta. The method of arriving at this relation is shown in Fig. 5. Each secondary winding is shown revolved 180 deg. from its primary, and the points connected together in this figure for making both the primary and secondary deltas, are the same as the points shown connected together in Fig. 4. Fig. 6 is the same as Fig. 5 except that in Fig. 6 the secondary is shown superposed on the primary as it would actually be in practice. If we assume that the primary and

secondary windings of the individual units are wound in the same direction around the core, then the points of the secondary delta would coincide with the points of the primary delta and would not have the six-phase relation. Another feature noticeable in Fig. 5 and Fig. 6 is that the points 1, 2 and 3 of the primary and of the secondary, while not coinciding, show the same rotation.



SKETCH D

We are now prepared to take up the main question as to whether the combination shown in Sketch B is feasible. Sketch D shows the individual transformer connections corresponding to the combination shown in Sketch B. The points 1, 2 and 3 of the primary represent the impressed voltage in Sketch B, and the transformer terminals upon which this voltage is shown to be impressed in Sketch D. Thus, of necessity, the primary

points 1, 2 and 3 of Fig. 7 and Fig. 9 must coincide, since the corresponding numbers of the figures represent identical voltage points. The question is: what relation shall we find where the two multiple circuits come together on the load bus?

Keeping in mind that the primary and secondary are wound in opposite directions around the core we find in Fig. 7 that the combination of secondary windings, each shown revolved 180 deg. from its primary, gives a delta lying in such a position as to bring together the points shown connected in the secondary of Fig. 7-*a*. The delta in Fig. 7 cannot lie in any other position

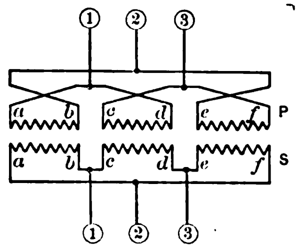


Fig. 9-*b*

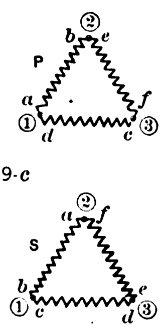
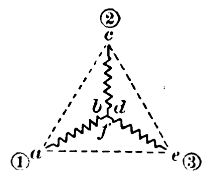


Fig. 9-*c*



S. OF Fig. 8 REPRODUCED

SKETCH E

than the own shown, and at the same time bring together the points shown connected in Fig. 7-*a*. The relation between primary and secondary, therefore, is fixed. The primary of Figs. 8 and 8-*a* is the same as the secondary of Figs. 7 and 7-*a*, the delta of Fig. 8 lying in the same position as the delta of Fig. 7. The individual secondary windings of Fig. 8 are shown, each 180 deg. from its primary, to form a definite Y corresponding to the connections shown in Fig. 8-*a*. Figs. 9 and 9-*a* show a delta-delta combination of single-phase transformers of standard polarity. It has already been pointed out that the primary

voltage figure represented by points 1, 2 and 3, Fig. 9, must coincide with the primary voltage figure represented by points 1, 2 and 3 of Fig. 7. In the secondary of Fig. 9 each winding is shown arranged 180 deg. from its primary, making a delta with points connected together as shown in Fig. 9-*a*, such that, if superposed on the primary as it actually is in practice, would give a six-phase relation between the primary and secondary.

The secondary points 1, 2 and 3 of Fig. 8 and the corresponding points of Fig. 9 are seen to be fixed in their positions. According to the conventional practice of connecting the two circuits, as shown in Sketch D, in multiple, the points numbered 1 would be connected together, the points numbered 2 connected together and the points numbered 3 connected together. But if we refer to Sketch B we find that in superposing Fig. 8 upon Fig. 9, the points 1, 2 and 3 do not coincide, but make a six-phase combination, which if connected together will give a short circuit on the impedance of the combination, the corresponding points of the two figures being 180 deg. apart. Furthermore, they cannot be made to coincide by varying any of the connections to either the high-tension or low-tension line.

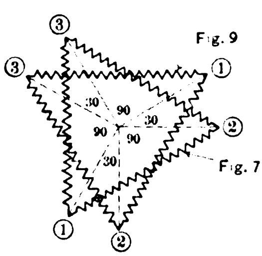
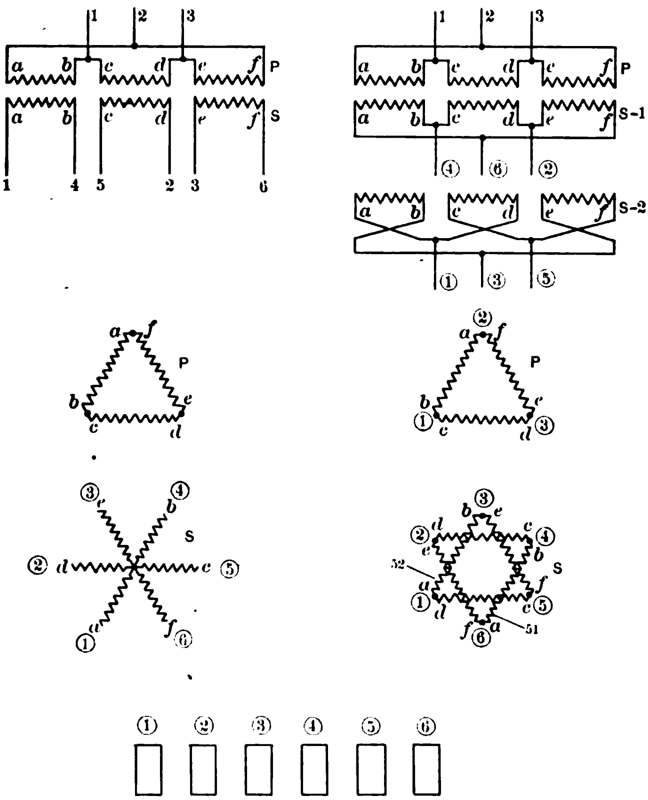


Fig. 13

By reversing the primary leads of the individual transformers of Fig. 9-*a*, Sketch D, as shown in Fig. 9-*b*, Sketch E, the points 1, 2 and 3 of the secondary of Fig. 9 are made to coincide with the points 1, 2 and 3 of the secondary of Fig. 8, as shown in Fig. 9-*c* and the secondary of Fig. 8 reproduced in Sketch E. A number of other problems that have arisen in practice may be explained in detail by the reasoning given for this instance.

It is generally understood that a Y-delta combination cannot be run in multiple with a delta-delta combination. Referring to Sketch B, the relations between two such combinations are shown in Figs. 7 and 9. Fig. 13 is used to show the secondary of Fig. 7 superposed on the secondary of Fig. 9. as it would actually be in practice. Referring to Sketch D, if the operator desires to make the trial of connecting the bank of Fig. 7-*a* in multiple with the bank of Fig. 9-*a*, he would connect the 1 leads together, the 2 leads together and the 3 leads together. But these corresponding points as shown in Fig. 13, are from 30 to

150 deg. apart. Furthermore, the phase rotation is reversed, so that to connect the corresponding points together would give a short circuit. It is commonly said that the secondary deltas in this instance are 30 deg. apart, but this statement is based upon the location of the points with the same phase rotation, and not upon the points that would ordinarily be connected in service.



ROTARY COLLECTOR RINGS

SKETCH F

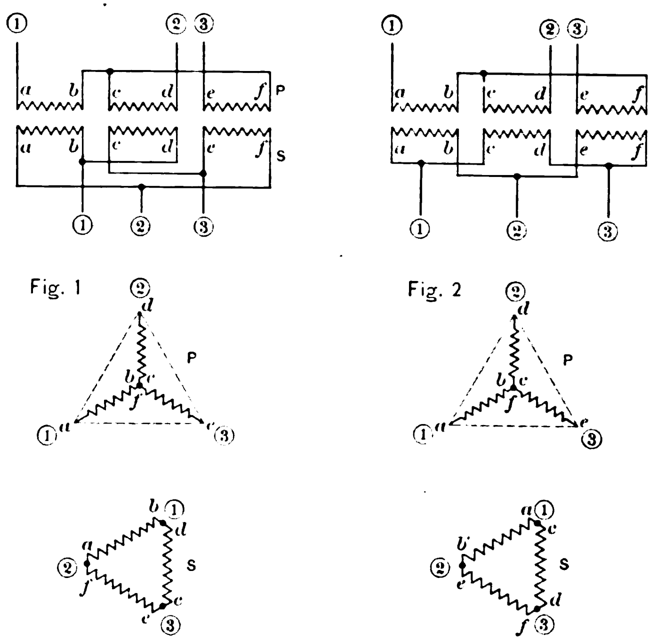
Sketch F shows the usual combinations of three transformers for obtaining a six-phase voltage for synchronous converters.

Fig. 1 of Sketch G shows a three-phase transformer that was desired to be operated in multiple with the one shown in Fig. 2. The connections were as shown, and it was known also that in the case of Fig. 1, the individual phases have their windings

wound in the same direction around the core, while the individual phases of the transformer shown in Fig. 2, have their primary and secondary windings wound in opposite directions around the core. It is seen from the sketches that the deltas of the transformers coincide and that the phase rotation is the same for both transformers.

CONNECTIONS THAT DEVELOP TROUBLE

Sketch I shows a combination of transformers and generator commonly used in large cities. In some instances the triple



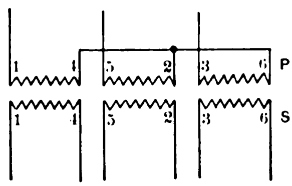
SKETCH G

frequency voltage established by the generator has been of sufficient value to cause heavy triple-frequency current to circulate in the delta of transformers for three-phase service. It is understood that the triple-frequency voltage does not appear between lines but only between lines and the neutral point. (See paper by J. J. Frank, PROCEEDINGS A. I. E. E., March, 1910). Therefore, the fourth wire connected to the neutral point for the distributing system, admits the circulation of the objectionable current in the windings of the transformers connected as shown in Fig. *m*, Sketch I. This no-load current

has been known to reach values ranging from 50 per cent to 90 per cent of the full-load current.

This objectionable current has been easily eliminated by simply disconnecting the fourth wire from banks of transformers used for three-phase service. If it is desired to ground the neutral of the distributing system the generator neutral may be grounded. This keeps down the static electricity usually noticed in stations where the neutral is not grounded. It is not necessary to ground the neutral of the bank of transformers for the motors.

Sketch H shows the combination of transformers for six-phase split-pole converter service. There are two sources of



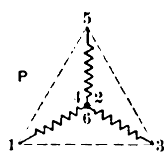
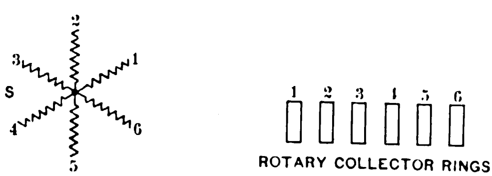


Fig. n

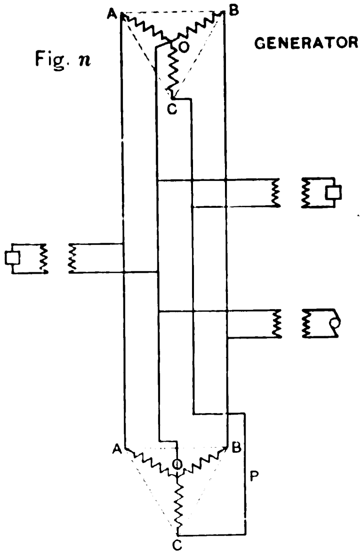


SKETCH H

triple-frequency current encountered in practice. In Sketch I it was shown that the triple-frequency effect originated in the generator. In Sketch H we have an instance of the appearance of triple frequency effect that results from the nature of the transformer. That is, any transformer may be so connected with other transformers as to show the triple-frequency effect inherent in all transformers. There was occasion to measure the secondary voltages with normal voltage impressed on the primary of the transformers shown, before the switch between the transformer and converter was closed. Each of the secondary voltages was found to be about 10 per cent higher than it

was rated. Thus, it appeared that the transformer ratio was incorrect, but this was not the case. Readings taken from the points 1, 5 and 3 to the neutral point showed that each of the leg voltages was greater than that corresponding to the line voltage from 1 to 5, etc. The neutral connection was found to have a different potential from that of the earth, notwithstanding that the leg voltages were equal. The voltage diagram of a

Fig. *n*



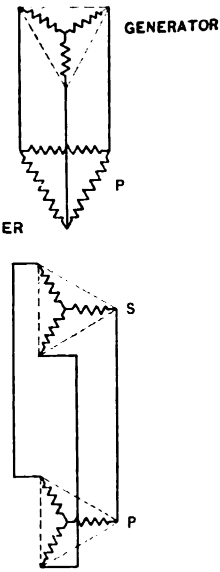
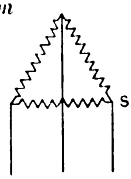
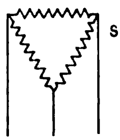


Fig. *m*



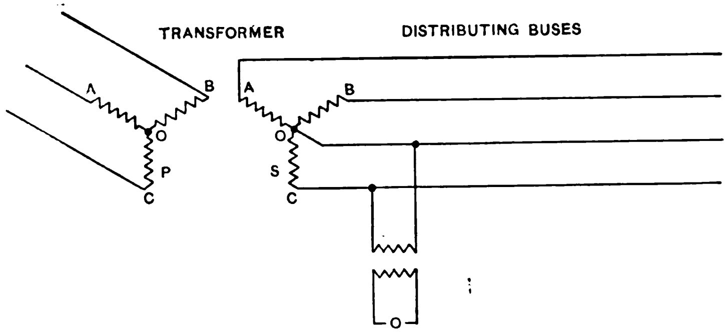
Sketch I



Sketch J

leg is shown in Fig. *n*, Sketch H. 5-2 is the measured voltage and 5-2′ is the leg value corresponding to the line voltage; so that 2′-2 at right angles to 5-2′ is the value of the triple-frequency component. This value holds true for each of the legs, and is best understood by considering the leg values in a plant at right-angles to a line passing through the true neutral point, the observed neutral being a point in the line out of the

plane of the legs. Thus, if the measured leg voltage is found to be 10 per cent greater than the value corresponding to the line voltage, then the triple-frequency would have an actual value of about 46 per cent, assuming the true leg value to be 100 per cent and the observed value 110 per cent. This means that if the secondary windings are connected in delta and one corner of the delta is opened the voltage found at the open corner is about 40 per cent greater than the rated voltage. The ratio of transformation was found to be correct, comparing the secondary voltage with the primary leg voltage which is the voltage of the primary windings of any one of the transformers making the three-phase combination. Upon closing the switch between the secondary and converter a small magnetizing current circulated in the converter winding and caused the transformer voltages to drop to their normal value, which means that the leg values



SKETCH K

of the primary corresponded with the line values in the usual relation.

Sketch J shows a combination used for long distance transmission of power. Any triple-frequency component in the generator voltage simply results in shifting the neutral of the generator in case the neutral is not grounded and in rocking the three-phase voltage impressed on the transformer in case the neutral is grounded. Its effect, except for this rocking back and forth of the voltage triangle, when the neutral of the generator is grounded, does not appear anywhere in the line. The question arises as to why, if we find a considerable voltage between open corners of the step-down delta, a current would not flow in the delta when it is closed, corresponding to the voltage observed divided by the triple frequency impedance of the transformers? It was seen in Sketch I that under a similar

relation of primary and secondary windings we observed nearly full-load current circulated. In Sketch J the triple-frequency voltage found between points of the open corner is due to the nature of the transformer, and therefore, only a very small magnetizing current is necessary to re-adjust the voltages. The current is inappreciable whether the neutral points are connected together or not.

Sketch K shows a combination of three single-phase station transformers for distributing purposes. The connection is $Y-Y$, and while not a common one, is used in at least two large cities in the United States, with this difference, that in one, both the high tension and low tension neutrals are grounded, while in the other only the low tension neutral is used for a fourth wire service. In the instance where the high tension neutral was not used, considerable trouble was experienced in the unbalancing of the phase voltages of the distributing system. If the load is perfectly balanced and the transformers used in the station have identically the same magnetizing current, then there would be no unbalancing of distributing voltage. However, experience has shown that it is practically impossible to obtain such perfect conditions and therefore this combination is bound to result in extreme unbalancing of voltages.

In order to understand why this combination is so easily unbalanced it will be assumed that current is being drawn between the fourth wire 0 and the point C, Sketch K. This current represents unbalancing and is drawn from the winding $O\ C$ of the secondary of a single-phase transformer in a three-phase combination. But there cannot be current in the secondary without corresponding current in the primary. Thus, in addition to passing through $O\ C$ in the primary, the current must also pass through either $O\ A$ or $O\ B$ or both. No current is passing through $O\ A$ or $O\ B$ of the secondary. Therefore, any current passing through $O\ A$ or $O\ B$ of the primary must be magnetizing current. Thus, with very small current delivered between O and C of the secondary, the voltage between O and C of both the primary and secondary becomes approximately zero and the point O extends to C.

The unbalancing of the voltages was eliminated by connecting a three-phase transformer across the distributing lines in such a way as to admit the circulation of the balancing current.

DISCUSSION ON "POTENTIAL STRESSES IN DIELECTRICS". NEW YORK, OCTOBER 17, 1910. (SEE PROCEEDINGS FOR OCTOBER, 1910.)

(Subject to final revision for the Transactions.)

J. B. Whitehead: The language of the ionization theory is conspicuously lacking in this interesting paper. Since this theory is now widely accepted, and since practically all of the phenomena of the conductivity of gases and many of those of liquids and metals may be explained in terms of this theory, it is worth while to consider in the same light some of the questions raised in the authors' valuable summary and discussion of the nature of the processes involved in the break-down of cable insulation. First as to the possibility of corona in solid dielectrics it must be remembered that the term "corona" has arisen in connection with the phenomenon in gases and that the structure of the solid is radically different as viewed by the firmly established kinetic theory of matter and its offspring the ionization theory. The important differences in the present instance are the greater number of free ions in a gas, the greater length of their free paths, and above all the possibility of an ion attaching itself to one or more molecules and dragging them through the gas under the influence of an electric field. Thus in the corona in gases it is certain that disruption or ionization occurs only within the bounds of the corona itself, yet beyond the corona there is motion of charged molecules the charges originating as free ions in the corona. Moreover it is highly probable that the gas even in the corona is not disrupted at all in the sense that the term means the separation under the electric field of the two component charges of an atom of molecule, but that these latter are split apart by the impact of a free ion of which there are always a certain average number present.

In the case of the solid dielectric on the other hand there is little, if any, evidence of the existence of free ions. The mean free path of the molecules is much shorter than that of the gas and it is certain that agglomerations of molecules attached to a free ion cannot move freely through the body of the substance. Further, it seems highly probable that the break-down of a dielectric is an actual disruption or tearing apart of the opposite charges of a molecule under the stress of the electric field. The long accepted view that the dielectric properties are due to an elastic structure of a molecule in which the two component charges are held together up to the point of disruption, is not in conflict with the ionization theory which simply states that there is no extended motion of free ions with consequent possibility of ionization by collision, and resulting conductivity.

What then does the theory offer in explanation of the facts observed in the behavior of cable insulation? These facts are: (*a*) The insulating material may be overstressed without breakdown. (*b*) There is no evidence of corona or charring of insulation. (*c*) There is no evidence of conductivity after overstress

or consequent increase of capacity due to such conductivity. (*d*) The material after overstress is, however, weaker.

There is no difficulty in the idea of a strain of dielectric material beyond the electrical elastic limit with no resulting structural break-down and resulting conductivity. In a single conductor cable, we may think of a string of molecules stretched radially along a line of electric force. When the interior portion of the insulation is overstressed, but the insulation as a whole unbroken we may think of the component charges of a molecule in the stressed region as drawn apart, and a tendency on the part of opposite charges of two adjacent molecules to combine. If this tendency could take place along the whole line of force there would be combination throughout and resulting discharge. The phenomenon would then be similar to conduction in a metal. In the case as supposed, however, the outer portions of the insulation are not overstressed, consequently proceeding outward from the conductor along the line of force there comes a region where there is a molecule which is not overstressed, which therefore successfully resists the tendency of one of its charges to pass to the adjacent overstressed molecule. This restraining influence is therefore propagated backward toward the center and serves to keep the overstressed portion from breaking down entirely. In this way the region of safe stress may be said to aid that in which this stress is exceeded. Referring to fact (*b*) it should be noted that the corona as it is known in gases with its evolution of heat is probably due to the rapid motion of charged particles or ions through the body of the gas. There is not the possibility of such motion in dielectrics and it is not therefore a necessity of overstress that there should be the carbonization usually resulting, in dielectrics from the passage of current. As to fact (*c*) it is evident that if there is no break-down and resulting conductivity there is no reason why increase of capacity should be looked for. There remains the fact (*d*) that the material is weakened electrically after being overstressed. In explanation of this it may be pointed out that slight impurities of material, particularly if such impurities have large conductivity, would serve to enable the opposite charges of adjacent overstrained molecules of the dielectric to be neutralized thus leaving an unbalanced molecule and a consequent region of weakness. This action would naturally take place in the method ingeneously described by the authors with the term "needle point".

With regards the question of the constancy of the electric strength of dielectrics it may be pointed out that there is plentiful evidence that in gases the electric stress may be carried far beyond the value which is taken as constant for the material for the great majority of circumstances. In those instances in which the gas seems to present abnormal strength it may be shown that the conductor applying the electric strain has dimensions so small as to be comparable with the mean free paths of the ions which are involved in the break-down of the

gas itself. Extending this idea to the case of dielectrics we are faced with the fact that the distances between the ions which enter into the phenomenon of disruption are very much smaller than those involved in the phenomena occurring in gases. It would therefore seem probable that by steadily decreasing the size of wire any tendency of the electric strength to present an apparent increase must occur at very much smaller diameters than those obtaining in the case of a gas. It is worth mentioning also that for the same reasons one might expect an alteration in the value of the specific capacity of the material for very small wires.

The paper has presented in valuable fashion the problems connected with the strains in the insulation of cables. It leaves the field in excellent shape as a point of departure for promising experimental work. It is to be regretted that the authors could not supplement their own deductions with more experimental evidence. The field, however, is notoriously a difficult one.

Milton Franklin: The subject of this evening's paper is of great interest to me inasmuch as I have done some work along these lines myself. I have prepared a paper on the analytical discussion of the physical dimensions of cylindrical dielectrics. My paper is mathematical rather than practical, though only the simplest mathematics are involved. Messrs. Osborne and Pender have applied these principles to commercial design, which is, after all, the ultimate aim of all such investigations.

My analyses, however, are fairly exhaustive and will enable any one to comprehend the principles involved and to extend their application to many cases other than the insulation of cables, and to cases of this, other than to those here treated, for example: the determination of the minimum mass of material that may be used in any case, etc.

The paper this evening is a very practical one, and in my opinion admits of very little criticism. The attempt to explain the cause of dielectric failure seems to me to be a description of observed cases rather than an explanation.

I have shown in the paper referred to, and in some subsequent experiments, that the dielectric stress corresponds to a mechanical stress similar to a hydrostatic pressure and accompanied by a proportionate strain, and have given an equation expressing the values of this stress, for various conditions in pounds per square inch. I am led to the conclusion that the failure is due to the periodic application of this stress, and the ultimate fatigue of the material. It is true that the stress and the consequent strain are small, but the number of blows is enormous, *e.g.*, at 60 cycles per second there are one hundred and twenty blows per second, 7200 blows per minute, 432,000 blows per hour, 10,368,000 blows per day, etc. This I think explains the cause of failure, the needle point result being due to lack of homogeneity and constituting the prodromata of an unstable equilibrium. The delay, or time lag, observed is not incompatible with this hypothesis.

With respect to the cases given for multi-conductor cables, I cannot agree with the assumption of the authors with regard to the distribution of charge. They seem to ignore the influence of electrical images and the oscillating character of the alternating current, for which, in the main, these cables are designed. With respect to images it should be noted that in cables the conductors are very near the ground, *i.e.*, the images, and the skin effect tends to a peripheral distribution of the charge. The moments of these quantities are not amenable to mathematical analysis and evaluation, but I am satisfied from observation of practical cases that the assumption of uniform peripheral distribution, while probably not exact, will lead to minimum errors. This applies also to practical cases of transmission.

A. E. Kennelly: The subject of this paper is of great practical importance owing to the rapidity with which voltages have been rising recently in electrical engineering.

The facts are very clearly presented in the paper. The paper has, moreover, the special merit of presenting curves, by means of which the advantages, theoretically obtainable from the grading of cable insulation can be read off on inspection. We should however, carefully distinguish between the advantages that may be theoretically obtainable, and those that may be practically obtainable, through grading. Many considerations, such as mechanical strength, elasticity, permanence, cost, etc., must be taken into account, besides the dielectric strength, in selecting gradings.

We all know that a joint in the magnetic circuit gives rise to a certain extra magnetic reluctance and c.m.m.f. But the paper shows that a joint in the electrostatic circuit may not merely be the seat of additional electrostatic reluctance, but also of a dangerous local electric gradient. Such electrostatic joints may be inimical, by introducing equivalent point conductors, where the dielectric may break down, as little spherical particles into conducting material, whence electric flux and electric equipotential surfaces may diverge anew with powerful local intensities into the adjoining layers of dielectric. For this reason also the paper indicates that a grading of insulation may be detrimental instead of helpful.

It must be admitted, however, that the particular kind of grading experimented with—the grading of rubber and glass—is more than usually dangerous in regard to weak electrostatic jointing. When a rubber-covered wire is pulled into a glass tube, there is sure to be a layer of air included between the two. This air has not only a relatively high electrostatic reluctivity, thereby establishing a relatively large drop of potential across the layer, but it has also a relatively low breaking stress. Once it breaks electrically, it is able to precipitate high local stresses near the broken down spots, as is described very clearly in the paper.

In making computations of graded electrostatic reluctances,

"semi-log" paper has special advantages, that is, paper ruled to logarithmic coördinates along the axis of abscissas, but to ordinary uniform spacing along the axis of ordinates. "Semi-log" paper can be constructed by taking ordinary cross-section paper, and laying off the spacings, from the face of a slide rule, along the horizontal axis. The long denominator in formula (3), which is virtually a summation of electrostatic reluctances in series, is then presented on "semi-log" paper in the form of a simple series of juxtaposed rectangles. The total area of all the rectangles is thus easily determined, and defines the total electrostatic reluctance of the graded insulation. The potential in the layers insulation also reveals itself on the "semi-log" diagram, as a series of connected straight lines.

In regard to the effect upon the electrostatic capacity of dielectrically stressing cable insulation layers, I may mention a case that came to my notice a few years ago. A stranded copper conductor 2.3 mm. in diameter, was covered with a layer of Pará rubber to a wall thickness of about 1 mm. and then covered with vulcanized rubber, containing over 40 per cent of rubber, to a total diameter of 7.15 mm. About one hundred 5-mile lengths of this core were tested. The tests included electrostatic capacity, and dielectric stress at 5 kilovolts r.m.s. pressure between conductor and outside salt water, for 5 minutes, at 60 ~. It was found that the core easily withstood this pressure, and no injury could be detected in the insulation after this application. The linear electrostatic capacity, however, which, before applying the dielectric test, averaged approximately 0.4 microfarad per nautical mile, was distinctly increased after applying the test. The increase was most noticeable immediately after the test, and partly disappeared with time; but an increase of about 5 per cent was found to persist, at least for months. In some cases the increase in linear capacity immediately after the test was 15 per cent. The capacity was measured by direct current methods, using (1) galvanometer deflections on charge; (2) galvanometer deflections on discharge; (3) the method of zero resulting charge by mixture.

W. S. Franklin: In discussing a theoretical paper on engineering one should attempt first of all to estimate the significance and value of the paper. In the present instance this duty is a pleasing one because in my opinion the paper constitutes an unusually important and really practicable application of theory to electrical engineering.

I have always looked upon the grading of cable insulation as an extremely simple matter, which indeed it is from the theoretical point of view. But the grading of cable insulation is not wholly a theoretical matter; the facts as to the electric strengths and inductivities of available materials are of some importance, to say the least, and Osborne and Pender are the first, as far as I know, adequately to consider the question of grading on the basis of these facts.

The case mentioned by the authors of a cable which contained four times the necessary volume of insulating material shows indeed the importance of their paper, and the fact that a person perfectly familiar with Maxwell's theory would be unable to point out this glaring case of bad design shows that something besides Maxwell's theory is necessary.

There is a close analogy between the mechanical cracking of strained glass and the electric rupture of a dielectric. The authors seem to have this analogy in mind when they speak of the "needle-point" theory. This analogy is developed in Nichols & Franklin's *Elements of Physics*, Vol. II, pages 154-157. The analogy holds for the ordinary spark discharge and also for the brush discharge or "corona," and it is not inconsistent with the electron theory provided one does not look upon the "needle-point" fracture as a mathematical line.

A difficulty in forming a mechanical conception of the influence of inductivity on the distribution of electric stress is that a mechanical arrangement *in parallel* must be compared with an electrical arrangement of dielectrics *in series*. Thus a number of helical springs of different degrees of stiffness are placed in parallel between two parallel metal bars. When these bars are moved towards each other every spring is subjected to the same strain or yield and the stress or compressing force is great in the stiff springs and small in the springs which yield easily. When a number of layers of dielectric are placed between two charged flat metal plates, they are all subjected to the same electrical yield (electrical flux density or displacement), the dielectrics which have great electrical stiffness (small inductivity) are subjected to great stress in volts per centimeter and those which have small electrical stiffness (large inductivity) are subjected to small stress in volts per centimeter.

The modern built-up cannon furnishes a close analogue to the graded cable. Indeed, if one could use highly elastic or easily yielding steel for the inner portions of the gun tube and less elastic or stiffer steel for the outer portions (ultimate strength of steel being the same in both cases) then the analogue would be complete. The interior portions of such a graded steel tube would yield greatly in being brought to their maximum permissible tension and this great yield would stretch the outer and less yielding portions of the steel tube sufficiently to bring the tension in these portions to the permissible limit. So it is in the graded cable; the inner portions of the insulation have high inductivity, that is to say, the inner portions are made of material which is electrically yielding, as it were, and the great yield (electrical flux density or electrical displacement) which is produced in the inner layers as compared with the outer layers of insulation causes inner and outer layers to be stressed simultaneously to their maximum strength in volts per centimeter.

W. I. Middleton: Considerable is to be gained by the grading of insulation of cables for very high voltages, say above

15 kilovolts, as it tends to decrease the wall of insulation and so reduce the cost of outside covering; but on lower voltages its advantage is doubtful, where grading might reduce the insulating wall to such an extent that for mechanical reasons it would be dangerous. Cables carrying from 10 to 15 kilovolts, where the copper runs from No. 1 to No. 4/0 B. & S., can easily be made with a good grade of rubber without putting too great a strain on the dielectric. Owing to the difficulty of making insulations of different specific inductive capacities when only one kind of dielectric is used, it would seem best in making graded cables to use a combination of two or more materials, such as rubber, cambric, and paper.

I am most interested in what the speaker terms "Corona in Solid Dielectrics.". I do not believe any of us knows what actually takes place in the dielectric, but as far as Professor Russell's hypothesis, that the dielectric near the conductor breaks down and becomes charred, is concerned, I do not believe it. In eight years in the testing room of a cable factory, I have never seen a cable that has shown mechanical change due to excessive voltage in either rubber or cambric insulation. I do not say that some cables may not be injured electrically by overstraining, but cables that are easily injured by voltage stress are to be avoided, as this injury shows that they have not been as well made as is possible. There is a vast difference in the characteristics of rubber compounds, which is not important for low-voltage cables, but is very important for high-voltage cables.

Now to come directly to the corona law and its application to cables, I agree to the commonly accepted formula

$$V = K\, d \log \frac{D}{d}$$

where V = test pressure.
K = voltage constant of the dielectric.
d = copper diameter.
D = diameter over insulation.

so long as the copper diameter is greater than 10/27 of the diameter over the insulation, that is, to the point where d equals $\frac{D}{2.72}$. Taking D and d in mils, we have tables showing the values of $d \log \frac{D}{d}$ for all sizes from No. 18 B. & S. to 1,000,000 cm., with walls from 1/32 to 20/32 in. on each size. We have used these tables to the critical point where d equals $\frac{D}{2.72}$, or approx-

imately where the copper diameter and insulating wall are equal, but beyond this point the formula does not apply.

For example, when the formula demands 45/32-in. wall on a No. 14 B. & S. wire for a voltage, on which 5/32-in. wall is adequate on a No. 4/0, we know this wall is not necessary. If the formula beyond this point does not apply, what formula does apply?

Having in mind the law for corona in air and the possibility of its application to solid dielectrics, I suggested that results be worked out with a modified formula, where d is changed to d_c

and $d_c = \dfrac{D}{2.72}$

$$\text{so that } V = K\, d_c \log \frac{D}{d_c}$$

This necessitated working out new values for our tables, and we began on No. 6 B. & S. for walls from 5/32 to 20/32 in., 5/32 in. being the point at which the wall of insulation is equal to the copper diameter. Inspection of the new tables shows a surprising feature, namely that the new values for $d_c \log \dfrac{D}{d_c}$ increased about 10 for each thirty-second added to the wall, while in the old table these values showed a gradual decreasing increment. As soon as we noted this feature, we made a further study of our formula, and saw immediately that the increase in value for 1/32-in. increased wall was a constant, regardless of the size of the cable, and calculation showed this constant to be 9.9855.

The two formulas agree that there is a minimum outside diameter for a given voltage, but they do not agree in the fact that while the old formula calls for an increase in the outside diameter with a reduction of copper, the modified formula allows for a reduction of the copper with the same outside diameter.

In a previous attempt to check up the old formula, we had made tests on a series of small conductors insulated with relatively thick walls of rubber, but the results did not agree at all with our calculations. On making a comparison of figures obtained by the modified formula with the old tests, we found that they checked up in a most satisfactory manner, and the modified formula has agreed with the results of subsequent tests.

It may be interesting to mention that instead of the 45/32-in. wall required on the No. 14 wire in the example given above, we now figure that only 9/32 in. wall is necessary.

Henry A. Morss: I would like to explain in a little more general way than Mr. Middleton has done, why he has de-

veloped his formula. When we first made cables, we had no means of knowing the necessary thicknesses of insulation except by experience, and if we wanted to determine the thickness for a cable on which we had no experience, we could only guess. Then we began to learn about this formula $d \log D/d$, and found that by taking its values and multiplying by a constant, which we could determine by experiment, we could arrive at a suitable thickness of insulation for any voltage. This worked very well, and we were much pleased with it until we began to figure small wires for high voltages. Then, as Mr. Middleton said, we came to absurdities; that is, they were absurdities to the extent that we knew we needed no such thicknesses. What we have been working toward, and have been trying to get, is some rule by which our calculated thicknesses will compare properly with the thicknesses obtained by experience, and this modified formula which Mr. Middleton has developed, seems according to our experience to date to enable us to figure these thicknesses which we could not figure before.

R. W. Atkinson: Assume as true (as seems probable) the author's theory that the overstressed portion of the dielectric is punctured in " needle points " and that the potential across this portion remains equal to that required to cause breakdown. Now the current across this portion is greater than the charging current at this voltage. The extra current is conduction current and is at right angles with the charging current and in phase with the voltage across this portion. The resultant current is then less than 90 degrees ahead of the voltage. Hence when this voltage combines with the voltage across the remainder of the insulation, the resultant is less than the numerical sum. The net result is that the capacity is greater than would be calculated by the method suggested by the authors and used as a basis for curve *c* in Figs. 10 and 12. This difference would not however be marked until the voltage is considerably higher than that which causes partial breakdown and would not be observable at all on ordinary cables with the usual insulation thicknesses, since there is not so marked a difference in the maximum and minimum stress as to make it possible to raise the voltage greatly above that causing partial breakdown.

Another thing which might be expected in the test is an increased dielectric loss when the conduction begins. It would be impossible to predict the amount of this since it is quite possible that the voltage across the needlepoint punctures is reduced considerably below that originally causing them. The destruction or carbonizing of the insulation by corona cannot be due to heat when the dielectric is uniform. Were it sufficient for this, the whole cable would heat extremely rapidly and the loss would have readily been observed in the wattmeter measurements both by the authors and by Höchstädter. (In *Elec. Zeit.*) The charring of insulation by discharges where there are air spaces is of a different nature.

H. W. Fisher: I will not attempt at this time to discuss the mathematics of the paper, but rather the experimental part in the light of recent investigations and reason.

During considerable experimental research work, I have never had any evidence which would lead me to the belief that the insulation next to the conductor in an overstressed cable becomes charred. It has been impossible to manufacture a cable whose insulation at all points will have an equal resistance to disruptive voltages. Hence, for sometime, I have believed that breakdowns of over-stressed cables must be caused, in the first place, by a gradual puncturing of the insulation around the conductor at the weakest point.

A knowledge of the characteristics of manufactured insulations leads one to the belief that an absolutely continuous disintegration of overstressed portions is impossible, and therefore, until an actual breakdown between conductor and sheath occurs, this action of isolated discharges must take place more or less all along the conductor.

I have noticed for many years that glass, overstressed at points by local discharges, breaks down under voltages much below what would ordinarily be considered safe. Generally, but not necessarily so, the glass is found to be cracked and I have been inclined to believe that the localized stress started a small crack through which a puncture immediately followed. The behavior of glass under localized electric stress very strongly accentuates my belief in the correctness of the authors' conclusions as to isolated discharges along the conductor.

Had other materials, such as a paper insulated conductor inside of a hard rubber tube, been used, I doubt very much if the difference between the normal puncture voltage of the hard rubber tube and that of the improvised cable would have shown anything like the difference found in the case of the glass tube specimen.

It must be remembered that in the tests under consideration, the materials used were chosen so as to accentuate the stress on the insulation next to the conductor. Therefore, in the case of a regular high-voltage cable, it is more difficult to determine what actually happens to the insulation if overstressed.

In a series of papers recently published in the *Elektrotechnische Zeitschrift*, Mr. M. Höchstädter gives the results of tests which show that the power factor increased very slightly with increase in the applied voltage, and that even at the puncturing voltage, there was no sudden increase of dielectric loss, which we would expect if there were a large number of discharges through the insulation near the conductor. Moreover, the general properties of the cable did not seem to be changed up to the instant when a puncture occurred. In the cable under consideration, the size of the conductor and thickness of insulation were such that the stresses on the insulation at the conductor would not be abnormally high compared with those on the insulation near the lead, and this may be the cause of the results obtained.

It would be interesting to make tests on an ungraded cable having a small conductor and considerable thickness of insulation and note if the dielectric loss increased rapidly when the insulation near the conductor began to be overstressed. Such a test I have had under consideration for some time.

One important fact must not be lost sight of, namely, that for mechanical reasons cables often have a thicker insulation than might seem necessary for the voltages under consideration.

The proper grading of the insulation of high-voltage cables is certainly of the highest importance and every up-to-date manufacturer will have his own way of doing this.

Percy Thomas: I will only add one suggestion. So far in the present discussion one of the very important elements governing the actual breakdown of insulating material has been practically omitted, that is the effect of temperature. Broadly speaking, in insulating materials, especially in some sorts of insulating material, an increase in temperature beyond a certain point, not far above ordinary atmospheric temperature, means a very great decrease in insulation resistance and more troublesome still a very considerable increase in the energy loss within the insulating material itself. The results of this fact may or may not actually be a serious matter, depending upon conditions.

Take for instance a comparison between the breaking down strength of a sheet of varnish covered paper one one-hundredth of an inch thick and the breaking down strength of fifty of those sheets piled together. The single sheet will stand perhaps 10,000 volts without trouble if the electrodes have not too sharp edges. Fifty of these sheets may very likely stand continuously not over 50,000 volts. This value might be a little higher if the material were well dried. Now as the number of sheets is multiplied by fifty and the breaking down voltage only by five there is a loss of possibly ten to one in the capacity of each sheet to withstand voltage. This effect is largely a result of the increase in temperature within the body of the material, not necessarily throughout the material, but at some particular spot or spots or layer. The higher temperature means that the energy loss will be larger which larger loss will cause the temperature to rise and this rise in temperature again increases the local loss of energy at that particular location and so on up and up. The heat resisting character of the material prevents the dissipation of heat fast enough to keep the temperature down. The result may be the entirely confined to one portion of the insulating material near the center, while the rest may be entirely uninjured. I have often observed such effects. Of course, extreme results are to be expected only under favorable conditions as where the insulation is very thick and has naturally a high energy loss under voltage stress.

This trouble is not met with in cables with the usual thicknesses of insulation under ordinary conditions, because they are used so far below the breaking down point of the insulation that

the energy losses are not sufficient to produce a material rise in temperature. It is only as we approach very close to the puncture point that the critical rise in temperature is found.

I think that it may be very likely that in the experiments described in this paper this local heating had a very important part in the final result, but it would be practically impossible to trace out this fact afterwards. I am not familiar with the thicknesses of material used, nor with other conditions of the test.

In tests of this sort, the time of application is of course extremely important as a certain elapse of time is necessary to cause a rise of temperature. The difference between the application of a static stress lasting but momentarily and a continuous application of alternating voltage is of course extreme.

The phenomena accompanying the case of two or more layers of insulation with a slight enclosed amount of air between, is a difficult one; but doesn't it seem probable that the heat generated in the thin layer of air by the fact that its insulation strength is overcome and the ions and corpuscles are freely moving therein and therefore generating heat, has much to do with the very serious weakening the total insulating strength of the combination found to accompany the presence of air layers?

If we were nearer the breaking down strain in cables, the effect of I^2R in the cable itself, due to the useful current flowing through the copper might be important. Fortunately, however, the cable has too good a radiating power for this loss to be critical, except possibly in the case where the grounding of one leg of the circuit occurs or excess voltage from some other cause subjects the cable to almost the puncture stress.

Possibly the effectiveness of the needle points in puncturing glass is very much emphasized by the point Professor Franklin has brought out, namely that we may easily have a minute crack started in this material. Now this crack is very likely due to the concentrated generation of heat, due to the extremely local application of potential by the needlepoint. Rapid heating of the glass at one spot would be almost sure to crack the glass at this point, the physical weakness of glass in that respect making it particularly vulnerable. This difficulty would not be found to the same extent in rubber or paper or cambric.

C. J. Fechheimer: The conditions which obtain in alternators are somewhat different from those which apply to cables, bushings and transformers, inasmuch as, due to mechanical considerations, we are practically compelled to place the conductor in a slot which is usually rectangular in section. The ideal condition, from the standpoint of insulation only, would be that of a round slot by means of which we would eliminate sharp corners on the coils. This, however, is impracticable.

In order that we may use as economically as possible the most valuable space in high voltage generators—that is, the stator slots—we often use conductors which are square or rectangular in section and to avoid the stress in the dielectric at the corners of

the coil reaching too great a value, the corners of the conductor are usually rounded.

It has often been contended that it is inadvisable to use mica for slot insulation and many engineers prefer only the use of cloth treated with some form of insulating varnish, but, as has been shown so well in this paper, it is extremely advisable to grade the insulation; that is, place mica or some other dielectric having a high specific inductive capacity near to the conductor and some other dielectric, such as varnished cloth, having a specific inductive capacity of about half that of mica, on the outside of the coil.

This grading of insulation enables us to use a smaller quantity and we thus can place more copper in the same size slot than we could if we used only varnished cloth for insulation. This also has the additional advantage that with a thinner insulation the heat can flow more rapidly from the conductor to the outside of the coil; and furthermore the mica, being near to the copper, is subjected to the highest temperature, and this material has the inherent property of being able to withstand high temperature far better than any kind of cloth.

The great advantage to be gained by placing the material having high dielectric strength, as well as high specific inductive capacity, next to the copper was brought out by Professor H. J. Ryan in his paper on "High Pressure Insulation" at the Electrical Congress in 1904, although he is inclined to believe that "structural requirements make impracticable . . . . . the placing of the most powerful dielectric next to the conductor".

We have since found, however, that we can without great difficulty surround the conductors with flexible mica and then use as a binder the varnished cloth or linen tape. A coil which was recently made on this principle in accordance with Mr. H. Pikler's advice, was wound with No. 8 B. & S. square wire having a radius on the corners of 0.026 in. The coil, after winding, was vacuum treated and was then wrapped with two layers of 0.012 in. flexible mica and then with two layers of 0.009-in. varnished cloth and one layer of linen tape. The coil was dipped in insulating varnish a number of times between wrappings. When subjected to a high-voltage test, this coil withstood a puncture test on one side of 29,000 volts and on the other side of 30,000 volts, these being effective values of voltage with a sine wave.

I was in hopes that I might reduce the density of dielectric flux at the corners, and thus increase the break-down voltage by placing tinfoil around the conductor, and also between the mica and varnished cloth and therefore had a coil wound similar to the one described above with the exception of placing tinfoil as stated, but found that this coil broke down at 16,000 volts; and another coil, which had tinfoil between the conductor and mica only, broke down at 20,000 volts. Violent brush discharge

indicated that the insulation was highly stressed before breakdown.

It would appear to me that the tinfoil has the effect of increasing the electrostatic capacity of the layer of mica and decreases that of the varnished cloth as implied in this paper, thus raising the potential gradient in the varnished cloth and decreasing it in the mica, causing the varnished cloth to break down, which resulted in the mica taking all the stress, and this broke down soon afterward. Had the tinfoil between layers of insulation proven a success as far as increasing the breakdown voltage was concerned, I would have expected trouble from eddy currents in the tinfoil due to changing in interlinkages with magnetic flux. This I thought I might be able to overcome.

In this connection I would call attention to the following statement in the paper: " Since these electric strengths are limited at present, in the manufacture of cables to very few values, they are not properly considered variable ". From the data which I have available, it is my impression that the dielectric strength of mica in volts per millimeter is nearly twice that of varnished cloth; so that for the ideal grading of potential we should be able to have the stress in the mica, in volts per millimeter, practically twice as great as in the varnished cloth. In fact, it appears to me that for ideal grading of insulation we should have the ***maximum potential stress in each dielectric proportional to its breakdown voltage.***

I would call attention at this time to a slightly different conception of the problem than that given by the authors in their paper. As stated by Professor Ryan and others, the breakdown of insulation results from the density of dielectric flux reaching a certain critical value just as in the case of material in tension or compression, a rupture occurs when the stress expressed in pounds per square inch, or similar units, reaches a certain critical value. It would seem that this view would give a clearer physical conception of the phenomenon than that of considering the breakdown to be due to the potential per unit thickness reaching a critical value. After all, as Dr. Steinmetz states in his book on " Transient Phenomena ", the potential is merely a mathematical fiction which is taken to be a measure of the electrostatic field, and we should therefore consider the stress in insulation to be due to the dielectric field rather than to the potential. Of course, for mathematical analysis it is far easier at present to treat the subject from the standpoint of potential rather than from that of dielectric flux.

From my point of view it appears that two dielectrics having equal strength expressed in volts per millimeter, but having different specific inductive capacities, the dielectric having the higher specific inductive capacity transmits more dielectric flux for the same difference of potential per millimeter and therefore its stress expressed in lines of dielectric flux per square centimeter is the greater.

If, as in the case of cables, we place a dielectric having a high specific inductive capacity next to the conductor and a somewhat lower specific inductive capacity dielectric outside of this first dielectric, then the first dielectric has the greater stress expressed in lines per square centimeter, although the volts per millimeter may be the same as in the outer layer of insulation. The effect of the outer layer in addition to taking part of the stress, is (due to its lower specific inductive capacity) to prevent as great a flow of dielectric flux as would be the case if all of the insulation were made up of the insulation having the higher specific inductive capacity.

G. I. Rhodes: This paper on potential stresses brings out three points to which I wish to call attention: the so-called corona effect, the value of graded insulation and the effect of heating by the load.

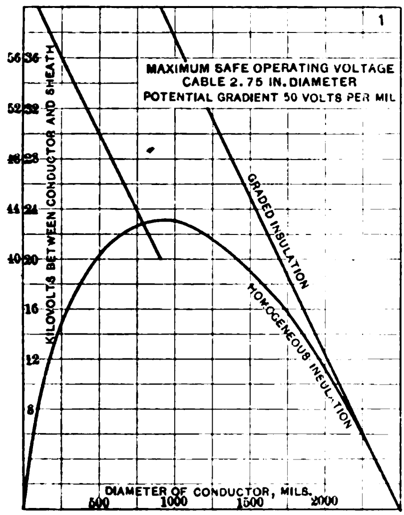


Fig. 1

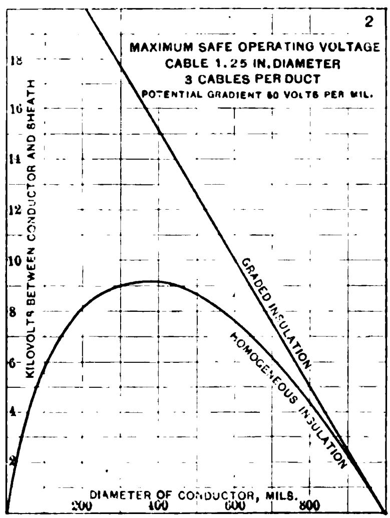


Fig. 2

The theory offered in the paper for the deterioration of insulation under excessive voltages, has an interesting bearing on the test voltages which should be applied to cables. These over-voltage tests are now applied on high tension cables at twice the working voltage for a period of 60 seconds.

When underground cables were first used, dielectric tests were frequently applied at voltages as high as three times normal for periods as long as half an hour. Breakdowns occurring during these tests usually happened within the first minute, but at times the cable held up for almost the entire test period. These breakdowns occurred with no apparent weakening of the rest of the cable.

The needle point deterioration, as explained in the paper, accounts for this phenomenon. If the deterioration was general these high voltage tests would have weakened the entire cable. The theory of failure in a gradually extending needle point explains both the time element and the apparent absence of damage to the rest of the cable.

In Table I the authors give an idea of the maximum voltages for which cables can be built. The limit of size is the maximum that can be drawn into a three-inch duct. I wish to call attention to the fact that high voltage is not necessarily the criterion by which to judge the value of a cable. In the future development of high tension underground transmission, it is probable that in addition to high voltage, a large safe load per duct will be called for. A small percentage loss will also be a factor. The cable will then be valued in proportion to its ability to carry load and inversely as the percentage loss at the maximum safe load.

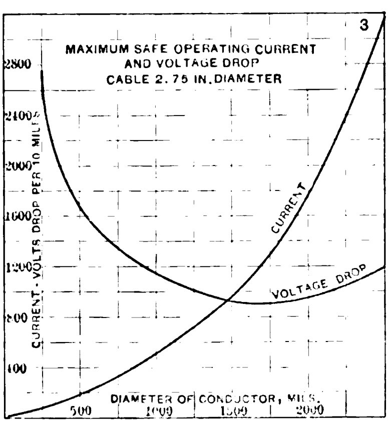


Fig. 3

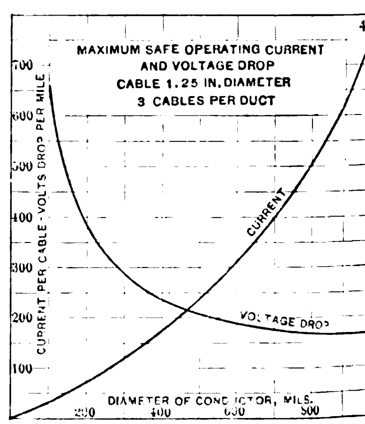


Fig. 4

I have prepared some curves, showing roughly the voltages, loads, losses, etc., in cables. The first type of cable considered is as large a single conductor as can be drawn into a standard duct. The second type is a single conductor, so large that three can just be pulled into a standard duct.

Fig. I shows the relation between permissible operating voltage and diameter of conductor in a cable of the first type. The figures are based on equation (2) of the paper. The voltage gradient of 50 volts per mil is safe for paper insulation. Curves are shown both for homogeneous insulation and for the ideal grading. It will be observed that there is a definite maximum voltage for homogeneous insulation, which obtains with a conductor diameter about 40 per cent of the total outside diameter of insulation.

Fig. 2 shows the same curve for the second type of cable, three to a duct. This type of cable was taken rather than the usual three-conductor cable, to simplify calculations. The results should not be very far different. It will be observed that the maximum voltage for homogeneous insulation again occurs at a conductor diameter of 40 per cent. The total actual value of the maximum is reduced by the small diameter of the cable.

Fig. 3 shows the maximum safe current in the 2.75-in. cable and the voltage drop due to this current. The effect of the relatively low heat conductivity of the insulation is taken into account. These curves are only roughly approximate.

Fig. 4 shows similar curves for the 1.25-in. cable. Here the currents are smaller, but current densities larger than in the previous case, principally on account of the thinner insulation.

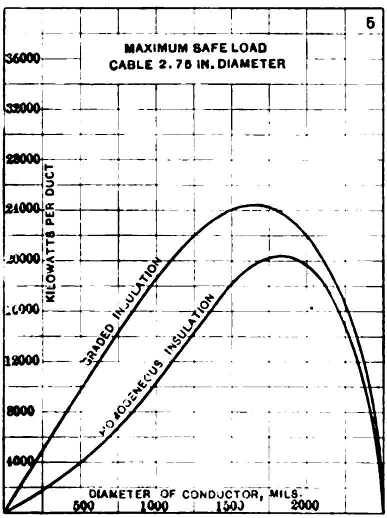


Fig. 5

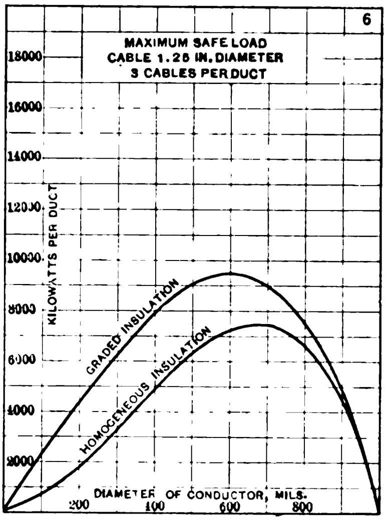


Fig. 6

Fig. 5 shows the relation between conductor diameter and maximum safe load on a 2.75-in. cable for the two kinds of insulation. It will be observed that the improvement due to grading the insulation is less here than on the voltage curves. The maximum loads require larger conductor diameters than the maximum voltage. This best diameter is approximately 70 per cent, instead of 40 per cent.

Fig. 6 shows similar curves for the smaller cables, three in a duct. Here the same general characteristics are seen as for the larger cable, except that the best conductor diameters are slightly lower.

Fig. 7 shows the percentage heating losses per mile in the large cable for the two types of insulation. Here the best conductor diameters are lower than for maximum load.

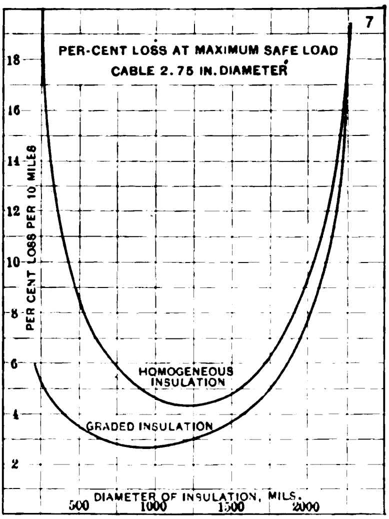


FIG. 7

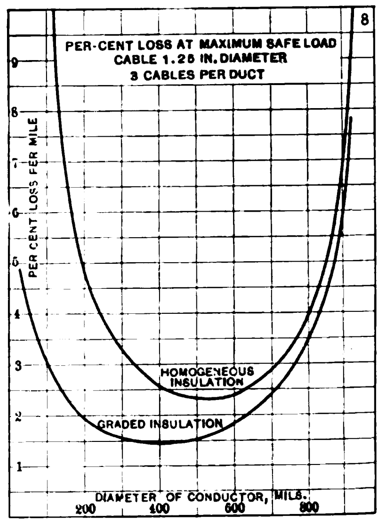


FIG. 8

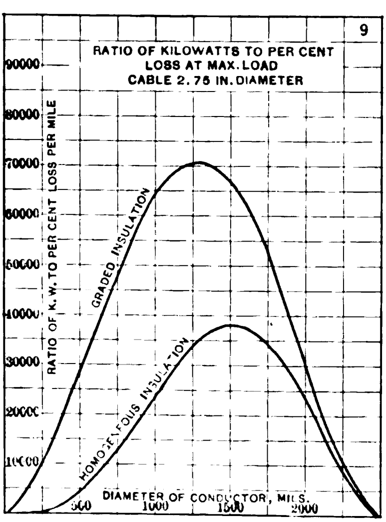


FIG. 9

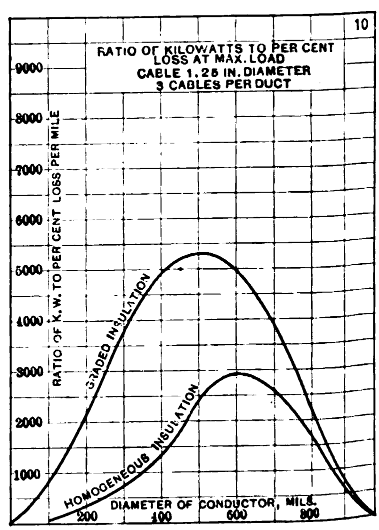


FIG. 10

Fig. 8 shows these same curves for the smaller cables. The effect of the high current density and the low voltage make the losses relatively high.

In Fig. 9 there are combined the loads and the losses, to get the measure of the value of the cable described at the beginning of this contribution. It is seen that the best diameter of conductor is from 50 per cent to 60 per cent of the total. Grading the insulation improves the cable about 80 per cent.

Fig. 10 gives similar curves for the smaller cables. It is seen that small cables are very much less desirable than the large. This is due to the lower maximum load and the larger losses.

To summarize the curves, it thus appears that the voltage to give the maximum capacity per duct is that corresponding to conductor diameter 70 per cent of the total, allowing 6,500 volts

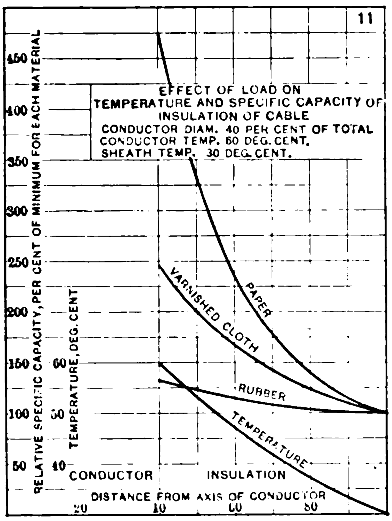


FIG. 11

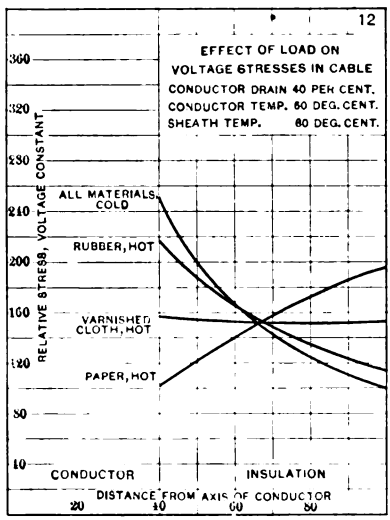


FIG. 12

for the three cables per duct and 18,000 volts for the large cable. The benefit from grading the insulation is small. For minimum drop the conductor diameter is about 45 per cent, corresponding approximately to the highest voltage permissible with uniform insulation, 9,000 volts for the three phase cables and 23,000 for the large, single conductor cable; the improvement due to grading being 60 per cent in such case. The best all-round cable is assured with a conductor diameter of about 55 per cent, corresponding to voltages of 8,000 for the three small cables, and 20,000 for the large single cables. The gain, due to grading is about 80 per cent.

If other than the maximum loads are to be considered, curves of somewhat different characteristics are obtained. These

curves show only maximum conditions. They show the cable that will transmit the maximum amount of power per duct with the minimum loss. Other considerations are neglected.

In the paper the effect of the temperature gradient in the insulation is mentioned, but no figures are given. Figs. 11 and 12 show the magnitude of this effect. They are based on data published by one of the large manufacturers of cables. Fig. 11 shows the variation of temperature and specific capacity of the dielectric with distance from the sheath.

The material used has a very great effect on the capacity distribution. Fig. 12 shows corresponding voltage stresses with a constant potential difference between conductor and sheath. The three materials considered show very well the effect of the temperature on the distribution of the strains. Rubber, which has a very small capacity temperature coefficient, shows very little change. Varnished cloth, which has a considerably larger coefficient, has a potential distribution corresponding closely to that in a perfectly graded cable. Paper, which has a still larger coefficient, shows a reversal of stress, so that the greater potential gradients are near the exterior of the insulation. This effect represents overgrading. If the safe voltage with a cold cable is taken as 100 per cent the safe voltages, after heating due to load as shown in the curves, are 118 per cent for rubber, 160 per cent for cloth, and 128 per cent for paper. It is thus evident that the cable is safer when cold, the factor of safety being greatest where the thickness and the capacity temperature coefficient of the insulation combine to produce ideal grading. If the temperature coefficient is too great, the stresses are inverted and then there is less improvement due to load.

If the cables are to be graded at all, this grading should take into account the temperature distribution in the dielectric, so as to produce the safest cable under conditions of full load.

Armin Henry Pikler: The authors in their very interesting paper properly started with quoting Maxwell. The fundamental phenomena in connection with dielectrics were observed by Faraday and the laws of distribution of the electrostatic flux in the dielectric of condensers of various configurations and finally the capacities of condensers of various configurations were given by Maxwell.

The results which Maxwell arrived at were not utilized for practical purposes until the necessity arose for them. It seems natural that the cable manufacturers, who were most pressed for room for insulation of cables, made first use of them. It was Professor Jona of Italy, who first made practical use of the idea of potential gradient and the grading of the insulation of cable.

From the analysis of two equations, the practical requirements for insulation between conductors arranged concentrically can be seen at once. From the equation: Potential difference equals charge divided by capacity, it will be seen that in con-

densers connected in series the one having the smallest capacity will have the greatest difference of potential between its conducting surfaces. From the equation giving the capacity of a cylindrical condenser $C = \dfrac{K\,l}{2 \log \dfrac{r_2}{r_1}}$ it will be seen that if the dielectric between the inner and outer conducting surfaces of the cylindrical condenser be divided into concentric layers of equal thickness, the inner layers—that is, the layers of the smaller radius—offer a smaller surface to the dielectric flux than the outer layers, when a charge passes from the inner to the outer wall of the cylindrical condenser. This results in a greater dielectric flux density per unit area on the inner layers. These layers will then have a greater difference of potential between the limiting walls and will be subjected to a greater stress. If the inner conductor is of very small radius, the stress in the layer of the dielectric close to this conductor will be enormous and there may be no insulating material sufficiently strong to withstand the stresses when this conductor carries a current of high voltage.

It is the above considerations which will lead to the design of the most efficient transformer insulation. I wish to discuss this subject more particularly from the point of view of the insulation and construction of high-voltage power transformers. The ability of transformers to transmit high voltages and to withstand very high voltage strains has developed practically during the last six or eight years and I dare say that this is due, not so much to a more thorough knowledge of insulating materials and the use of new materials, as to the recognition of the great dangers of moisture in the insulation, the capability of extracting this moisture and afterwards keeping it out of the insulation.

I wish to state that I do not consider it practical to use graded insulation in transformers between the high- and low-tension windings or between the windings and the core. The introduction of metallic layers between high- and low-tension windings would result in very great complications as regards manufacturing, and the connection of these metallic layers to taps of the high-voltage winding would add a number of high-tension leads, the placing of which would be cumbersome and the insulation of which would require a great deal of room and involve expense.

The grading of the insulation of a high-voltage cable is a matter of necessity because the unequal distribution of the dielectric flux and the great difference in density of the dielectric flux between points on the inner layers and the outer layers of the cable cannot be eliminated.

In high-voltage transformers, if properly designed, this unequal distribution of the dielectric flux density can be almost entirely eliminated and therefore the grading will become unnecessary.

Moreover, while in cable insulation economy of space is highly desirable, particularly from the point of view of cutting down the thickness and weight of the dielectric, the most expensive of the materials; in transformers a certain minimum space must be allowed between high- and low-tension windings and between windings and core to serve as ventilating ducts, admitting the circulation of oil between these parts. This results in low heating and consequently reduction in weight of copper, the most expensive of the materials used in transformers. This space, which is necessary for the purpose of cooling, is in most cases of ample size for the purpose of insulating the present commercial transformers of the very highest voltages, if properly designed and constructed.

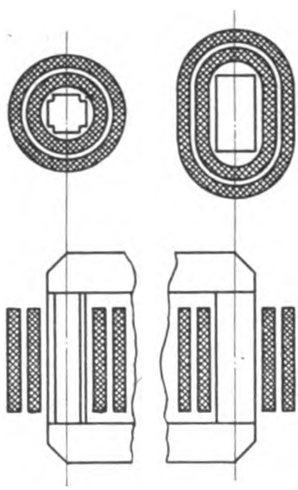


Fig. 1

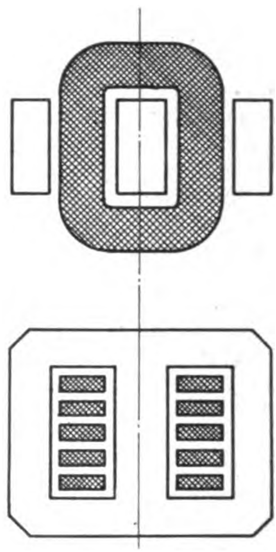


Fig. 2

The type of transformer where the distribution of the dielectric flux between high- and low-tension windings is most uniform is the one where the coils are arranged as concentric cylinders, either of circular or oval cross section. These two cylinders are placed over the sheet steel core in such a manner that the high-tension winding is outside of the low-tension winding. The opposing surfaces of these cylinders are either parallel walls or concentric circles of large radii. The percentage increase between the inner and outer radii being very small, the distribution of the dielectric flux between these surfaces will be fairly uniform and every cubic inch of dielectric will withstand the static strains in the same measure. The results will be a high factor of safety against breakdowns and economy in space and insulating material.

It will be only at the ends of these comparatively long cylinders that the density of the dielectric flux will be greater and its distribution irregular. These ends, however, being accessible, may be easily protected from breakdowns.

The type of transformer particularly adapted to employ coils and insulation as described above is the so-called core type transformer shown in Fig. 1. In contrast to this type, Fig. 2 shows another type of transformer winding, the so-called shell type. In this, the number of edges and sharp corners exposed between adjacent high- and low-tension windings and between windings and core are numerous. The dielectric flux density at these places is very great and it is difficult to insulate such windings. Nevertheless there is a great number of transformers, which employ coils of this type. The necessary insulation, however, and the space occupied by it is much greater than in the previously described core type transformer. For instance, in a 25-cycle, 2000-kw., 50,000-volt transformer of the core type construction the space factor of the windings—that is, the ratio between the total section of copper conductors to the total available winding space—will be about 27 per cent, whereas in the shell type transformer this space factor is only about 16 to 18 per cent. The consequence of this is a heavier and more expensive transformer for the shell type, about one-third more than in the case of the core type transformer. With this there also goes a lower efficiency and a worse regulation for the shell type transformer on account of the larger spacings required.

C. P. Steinmetz: This paper deals with a subject which has become very important, since the development of the electrical industry has led to the use of cables of 20,000 volts and more, and of transmission lines of 100,000 volts and over, and thereby made it necessary for us to seriously consider the phenomena of the electrostatic field. I entirely agree with Dr. Franklin, that it is of the utmost importance that we should endeavor to explain all phenomena in the simplest possible manner, and in such a manner as to get a clear physical conception of them, since only hereby it becomes possible intelligently and safely to use them. It is regretted therefore that the nomenclature and to the conceptions of the electrostatic field, electric intensity, electrostatic quantity, etc., are so cumbersome and so unamenable to giving a clear physical conception that we find it much more difficult to understand phenomena of electrostatic fields than for instance phenomena of the electromagnetic field. You can get a very simple and clear conception even of a very complicated magnetic field by Faraday's physical picture of the lines of magnetic force, and there is no reason why we should not get the same clear conception of the electrostatic field by a corresponding picture of the lines of dielectric force.

The first part of this paper deals with the question of grading in relation to cables, and the results and data given in the paper are very suggestive. But I believe we would make a mistake

if we should use them as given, for the design of cables, for the reason that the conditions are much more complex than they appear from the discussion in the paper.

High-voltage cables probably never break down by their operating voltage, but they break down at a weak spot, an air bubble, a lack of homogeneity in the insulating material; or they break down by a transient over-voltage, an electric impulse of limited power but more or less unlimited voltage.

As regards the first, you see that fundamentally important in the design of cable insulation is the mechanical character of the insulating material, as thereon depends the probability of applying it without getting any weak spots or defects in it. An insulating material may have a very high specific capacity and high disruptive strength, and may therefore appear very suitable for the inner core of a cable, and still be entirely unsuitable, due to its mechanical characteristics which make it less safe to rely upon the absence of weak spots or defects in it. This very greatly limits the variety of materials which can be used.

As regards the second feature, when the breakdown is due to a transient voltage, it means that of equal importance with the two quantities considered in the paper—the specific capacity and the dielectric voltage—the *dielectric energy* of the insulating material enters into the design of a graded cable. It takes a finite amount of energy to break down a dielectric and the dielectric may be exposed to an electrostatic gradient far above the break-down gradient without breaking down or deteriorating, if the application of voltage is sufficiently short that the energy of the field is less than the break-down energy.

This makes the problem of grading very much more complex than it appears on the surface, when we consider that this latter quantity, the dielectric energy, is of equal importance to the two quantities considered, while quantitatively we know practically nothing about it.

The explanation of the deterioration of insulation when stressed beyond its dielectric strength, by the formation of pinholes, I do not consider as a hypothesis, but rather as a fact, fairly well known for some years. In the early days of the application of high-voltage cables it was suspected from the life history of these cables, that a deterioration of the insulation took place by the formation of pin holes, and evidence of this phenomenon was afforded by the investigation and study of the insulation in very high-voltage transmission systems. In those cases where the insulation had been locally strained beyond its dielectric strength under conditions where no secondary phenomena, as short circuiting arcs, had destroyed the evidence, it is common to find the surface perforated by innumerable pin holes which, in the case of a very high voltage transmission line, where the electrostatic energy is large, may reach visible size. If then the over strained insulation is perforated by pin holes, either

microscopic or visible, the electrostatic field is brought to bear on the outer insulation in a concentrated form and the outer insulation is exposed to what we may call an electrostatic shearing strain. That explains the described break down of the glass tube at a voltage far below that which it would stand when exposed to a uniform static field.

This phenomenon has been described a number of times in recent years. It is shown best if you test a thin sheet of mica between a point and a plate. The mica sheet breaks down at a certain voltage. If now you put a drop of oil on the point, even a very small drop of oil, you find the mica sheet breaks down at a much lower voltage. In the first case, brush discharges spread from the point over the mica and give a gradual slope of the potential gradient. In the last case the drop of oil, by its much higher dielectric strength, cuts off the formation of the brush and brings the voltage localized to bear on the dielectric and the electrostatic shearing strain, if I may use that term, cuts through at a much lower voltage than a more uniform field would. You know that this phenomenon is guarded against in cable installations by avoiding sharp edges of the dielectric; by tapering it at the cable ends.

I agree with the authors of the paper that probably the phenomena leading to the corona in air are of the same nature as the deterioration of the solid dielectric by overstrain. The corona, my experience led me to believe, also is a disruptive effect and consists of innumerable minute streamers, the same as the pin points which perforate the solid dielectrics, the difference being merely that with the air those pin holes heal again, but they do not heal in the solid dielectric.

In discussing the break down of a dielectric by an overstrain we generally assume, and I believe correctly, that there is a finite dielectric strength to air, to solid dielectrics, etc. Usually the break down is explained by assuming that if at any point in the electrostatic field, the electrostatic gradient exceeds the dielectric strength of the material, a break down occurs at that point, and then may spread further if the conditions are favorable. Since on conducting wires the maximum potential grading is at the surface of the wire, the break down should occur at the wire surface as soon as the electrostatic gradient at this surface exceeds the dielectric strength of air. Calculating, however, the electrostatic gradient at the conductor surface from the voltage at which corona formation begins—and this voltage can be determined with great accuracy—we find that this electrostatic gradient is not constant but increases very greatly with decreasing size of wires. This has been explained by assuming a layer of condensed air on the surface of the conductor. I believe I am responsible for this explanation which I gave seventeen years ago in a paper on the dielectric strength of air, and I am the more sorry to say that investigations which we made during the last months have led me to doubt this explanation.

In the pursuit of a very extensive investigation of the phenomena of the electrostatic field in air and other dielectrics —of which we may be able to communicate some of the results at the next annual convention—I began to question whether the break down in the electrostatic field does take place as soon as the potential gradient exceeds the breakdown strength of the dielectric at any point. The results rather led me to suspect a different law. "In an electrostatic field a break down of the dielectric occurs as soon as the potential gradient has exceeded the dielectric strength of the material within a volume sufficiently large that the discharge current within that volume has an appreciable value. Corona thus forms at a conductor not as soon as the dielectric strength is exceeded at the surface, but only after the potential gradient has exceeded the break-down strength up to a certain distance from the conductor which is sufficiently large that the current charging and discharging the volume of air within this distance has an appreciable, though minute value."

This explains the increase of the potential gradient with a small conductor and also agrees with other phenomena which apparently contradict the assumption of the constant break-down gradient of dielectrics.

When there is an explanation suggested as the result of experimental evidence, it is always well for a moment to set aside the experimental results and reason what we should expect from the known properties of things.

When a break down occurs in a dielectric it means that in that broken down space a current flows. Now what are laws of current flow in air or other gases or in those materials which are used as insulating materials, in solid dielectrics. We find that the effective resistance is not a constant but is a function of the current density and has an enormous negative coefficient; that is, the resistance increases enormously with decreasing current density, approaching or tending towards infinity for zero current.

Now you see what could follow from this. If the break-down strength is exceeded at one point or a very small volume, the dielectric may be stressed beyond breakdown, but there can not yet be a current flow, since that current would be so small that the resistance of the material is too high, that is, gives a higher potential consumption than the potential gradient available in that space. You must first break down a sufficiently large volume to bring the resistance of the dielectric down sufficiently to pass the current. Thus the very phenomena which I outlined above should be expected from the laws of gas conduction and from the laws of the conduction of those dielectrics which are used as insulating material.

To conclude, I desire to congratulate the authors, not only on the very important results which they have communicated to us, but also on the very scientific manner in which they have given the results of their investigation by stating the experimental

facts, as such and without detracting from their value by giving instead of the facts their interpretation by some prevailing theory or speculative hypothesis.

C. O. Mailloux: The remarks made by Mr. Thomas caused me to recollect some interesting experiments which I made thirteen years ago. I had gone to Vienna to investigate a certain insulating compound. I utilized there the facilities placed at my disposal by Professor Grau of the Technical High School of Vienna. Together, we made some experiments for the purpose of demonstrating and determining approximately, (which was all that was possible, with the crude methods and knowledge at that time available to us), the relative resistance to puncture of different insulating substances. The particular compound which I was investigating specially was a mixture intended to replace and to constitute a substitute for gutta-percha. Hence I naturally compared it with gutta-percha. Inasmuch as that compound was intended to be used largely for making cables, I also compared it with several other compounds which were then on the market, notably the "wax" compounds used by Siemens & Halske for high-tension cable insulation. We made some experiments by taking sample sheets of the material of varying thickness, from a half a millimeter to seven or eight or even ten millimeters thick, and maybe from ten to fifteen centimeters square. We subjected these samples to puncture tests by placing them in the spark-gap of an electrostatic machine. As nearly as we could estimate, with the facilities we had, we were able to raise the pressure to as high as 50,000 or 60,000 volts, and to reduce it to 10,000 or 15,000.

The usual method of procedure was to lay the plate of material flat on a plate of metal forming one electrode or sometimes on a point, that is, allowing it to rest on one of the electrodes. We used vertical electrodes of various forms, some of the needle-point variety, some of the "knob" variety. We placed the electrodes near to or far away from the sample, according to the case, but always had the conditions the same for each set of experiments. By raising the voltage we could increase the stress; and, usually we would keep up the stress until puncture took place or until we found that the voltage was insufficient for the particular case. It should be stated that the pressure used was usually sufficient to cause brush discharge and sparking discharges over and around the edges of the sample. Now, I observed repeatedly that before puncture took place in any of the waxy materials, or in any compound, (*i.e.*, any "made-up" compound) there was always a slight preliminary *pitting* produced at the point where the puncture was to occur. After that pitting action began the puncture would occur generally (perhaps invariably), in a very short time. The idea occurred to me that there must be two actions here—a mechanical action, and a thermic action. So we tried the experiment of stopping the test before the puncture took place. First, by a series of

experiments we determined that a puncture would take place in so many seconds or minutes, as the case night be, with the application of a certain voltage; *i.e.*, we had found out what pressure was requisite and how long it must be kept up in order to produce punctures. I came to the conclusion that the puncture took place at a certain point which was first *heated* either by the passing of a very weak current resulting from dielectric hysteresis or by some slight conduction-current actually passing through the plate, which had the effect of heating it slightly. The moment it heated, the resistance decreased very greatly as is the case with all insulating materials of that kind, thereby allowing a still greater amount of current to pass through. Suspicious that this might be the explanation, we tried the experiment of removing the stress. After subjecting the plate to a high voltage for a certain short time, we would stop just short of puncture. We did that many times, and we noticed that if we allowed the plate to cool it would eventually recover very nearly if not all of its power to resist to puncture. Of course whenever pitting had already occurred the total thickness of the sample was diminished at the pitted point and consequently less pressure and less time were required to produce puncture. This led me to believe that the puncture took place, when it did occur, as the result of a lowering of the resistance which allowed the dielectric resistance to fall to such a point that actual conduction took the place of electrostatic conduction.

Another point which I wish to call attention to is that, in Europe, at least, there is a quantitative estimate or measure made of the difference in the breaking down ability of alternating current and direct current. At the Marseilles Electrical Congress in 1908 the question came up before the Section at which I presided, and, at the request of one of the members, I appointed a committee to interview the various cable manufacturers represented at the exposition or at the congress and ascertain from them what difference, if any, they would make in the margin of allowable potential if the current used were a direct or continuous current instead of an alternating current. One of the reasons which led to the discussion of this subject and to the appointment of the committee was an interesting exhibit made at Marseilles in which an alternating current of very high potential, something like 100,000 volts, was commutated and then applied to a cable. I believe the manufacturers dared anybody else to try such a voltage on their cables and especially to try it in the alternating-current form. The next day after the committee was appointed it reported at the meeting of the session; and my recollection is that every cable manufacturer had stated that a much higher voltage would be allowed if the voltage were "direct-current." The figures are probably to be found in the official report of the discussions before that section (*i.e.*, Section II) of the Congress. My recollection is that the figures ranged from one and one-half to two or more times the voltage. In other

words, the cable manufacturers were willing to allow from fifty per cent to one hundred and fifty per cent more voltage in the form of direct current than of alternating current. The discussion of the report of the committee led to an expression of opinion by several members familiar with this subject, to the effect that the strain produced by an alternating e.m.f. is at least proportional to the maximum value of the potential difference during each cycle, if not greater.

Tracy D. Waring: In the development of any theory it is well, and generally necessary, to begin with the simplest assumptions. The simplest theory of graded cables assumes that, for a given insulating material, we may assign to it a *definite* resistivity and a *definite* electric permitivity, or to speak in terms more familiar in the practice of cable engineering, the theory of graded cables requires that we know, for each insulating material, the value of those electric quantities with which the ideas

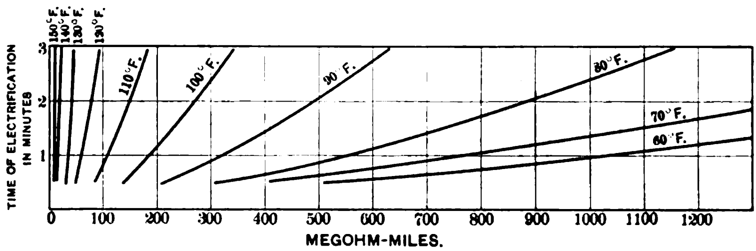


FIG. 1.—Showing change of insulation resistance with change in duration of electrification for various temperatures. Based on the assumption that under constant voltage the leakage current is a measure of the insulation conductance.

of insulation resistance and of electrostatic capacity of cables are associated.

Now it is well known that these qualities, for a definite insulating material, as determined by the customary commercial methods of testing, are anything but constant. The megohm-miles and the microfarads per mile for a given cable vary with the time of electrification and with the temperature.

Figs. 1, 2, 3 and 4, derived from tests on rubber insulated wire may be taken as typical of the change of insulation resistance and of electrostatic capacity with change of temperature, and different durations of electrification or charging.

It is worth while to consider how far the electrical qualities thus determined are applicable to the theory of grading, both for direct current and for alternating current voltages.

Under constant voltage the insulation resistance increases very considerably with the duration of electrification, (see Fig. 1) but at a different rate for different insulating materials, so that for a graded cable, made with layers of different materials,

the potential gradient from conductor to sheath cannot remain unchanged after the voltage is applied and in fact it may be hours before a steady state sets in. Evidently also, under direct current voltage, the voltage gradient changes with alterations of temperature; for the insulation resistance of different materials have different temperature coefficients, so that, for a graded cable subjected to direct-current voltage, the voltage gradient in the various layers would be different at different temperatures.

Under present industrial conditions, however, the chief practical interest pertains to grading for alternating voltages, and in view of the curves in Fig. 1. it may well be asked whether the insulation resistivity under alternating voltage is of a magnitude any where near that usually ascribed to insulating materials, such, for instance, as the figures given in the paragraph following equation (9) for rubber and for paper.

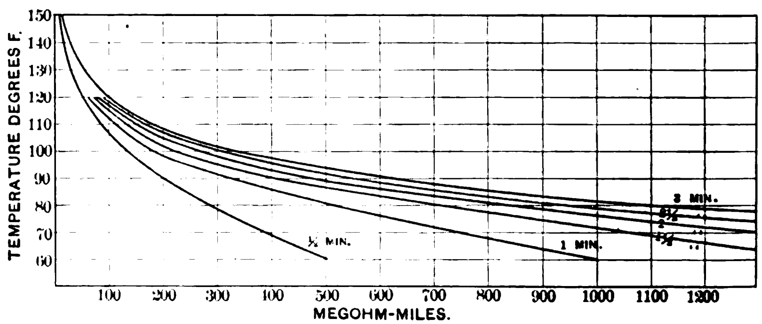


FIG. 2.—Showing change of insulation resistance with change of temperature for various durations of electrification. Based on the assumption that under constant voltage the leakage current is a measure of the insulation conductance.

Note in Fig. 1 how extremely low the resistance is for a short period, say one-half minute, as compared with three minutes. One is tempted to exterpolate at the lower limits of the curves and assume that, for very short intervals of electrification, say for one-half a cycle of alternating current, the resistivity of the dielectric would be extremely low, so low in fact as to make the resistivity and not the electric permitivity the determining factor in the voltage distribution in the dielectric, and thus to contradict the statement, " that in ordinary cases the conductance is negligible."

Exterpolation is, however, extremely dangerous and definite experimental figures for resistivity for short periods of electrification should be demanded to decide this question. A limiting minimum value for the " ohmic " resistance of a cable under alternating-current voltage may be obtained from a

consideration of the dielectric energy losses under known voltage and charging current. It is to be borne in mind, however, that the figure thus arrived at is simply the equivalent effective resistance and is not the true resistance, for the greater part of the dielectric losses are hysteresis losses and not generally attributed to the true resistance. The true effective " ohmic " resistance cannot, however, exceed the figure thus obtained. Calculations of specific cases made on this basis generally show that the effective equivalent resistivity, although hundreds of times lower than the " ohmic " resistivity at one minute electrification, is still so high as to indicate that the resistivity is not the determining factor for the voltage gradient under ordinary frequencies.

Although (in view of dielectric hysteresis) the true effective ohmic resistivity cannot exceed the figure thus calculated, it is

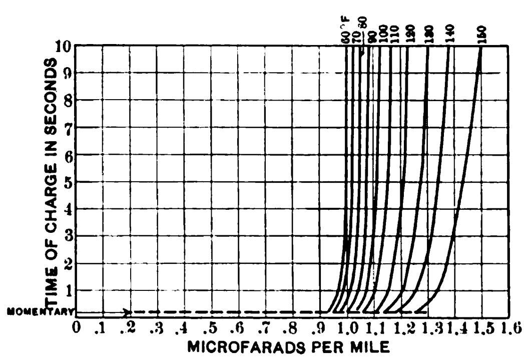


FIG. 3.—Showing change of electrostatic capacity with change in duration of time of charging at various temperatures. Based on the assumption that the discharge measured by the throw of a ballistic galvanometer is a measure of the electrostatic capacity.

conceivable that at some critical instant of the alternating cycle that the instantaneous resistivity might be much less than the figures thus arrived at. That this is improbable is beautifully shown in the oscillograph records presented by Höchstädter[1] and as pointed out by him it is an extremely interesting fact that, in spite of dielectric losses during the cycle, that at the exact instant when the applied voltage was at its maximum the current was zero, from which it may be concluded that, at the instant of greatest danger to breakdown, it is not the resistivity of the insulation which determines the voltage gradient.

I think it may be said, however, that we know very little of the true resistivity of dielectrics under extremely short periods of electrification, the displacement current and the leakage cur-

1. *Elek. Zeit.* May 12–19–26 and June 2, 1910. The results referred to were obtained on impregnated paper insulated cables. Tests on other materials might lead to different conclusions.

rent being difficult to differentiate, and I believe the dielectric losses under the same condition have never been analyzed experimentally into conduction losses and hysteresis losses.

Consider next the electrostatic capacity tests as shown in F gs. 3 and 4. The length of time designated as " momentary " refers to the mere tapping of the charging key thus charging the cable for a brief period and immediately discharging it through a ballistic galvanometer.

The capacity thus measured might be expected to give a suitable figure for calculating the charging current under alternating voltage. It has often been remarked however that the capacity calculated from the mean effective charging current and voltage does not accord with the capacity measured ballistically. It has been shown experimentally by Höchstädter, from

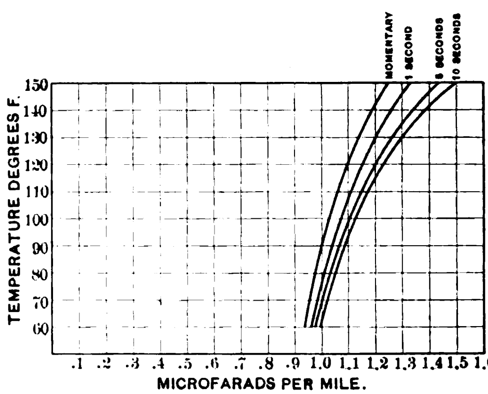


FIG. 4.—Showing change of electrostatic capacity with change of temperature for various durations of time of charging. Based on the assumption that the discharge measured by the throw of a ballistic galvanometer is a measure of the electrostatic capacity.

oscillograph records of tests on paper cables, that the discrepancy disappears if the capacity be calculated from the maximum instantaneous value of the voltage and from the charge in the cable at that instant. This agreement only holds, however, for capacities measured ballistically at rather low temperatures. As a matter of fact the experiments just referred to showed that the electrostatic capacity measured by the charging current is constant, and independent of the temperature. That is, it may be inferred that the electric permitivity is a true constant independent of the temperature and does not change with the temperature at all in the way that is indicated by the ballistic capacity tests.

The bearing of this point on the grading of cable is evident since it has commonly been supposed that the dielectric permitivity varied with the temperature and thus, for instance, an

ungraded cable, when heavily loaded would become automatically equivalent to a graded one, since the temperature next the conductor would be higher than at the sheath; but if electric permitivity is independent of temperature this would not be the case, and in any cable the voltage gradient in the insulation, under alternating voltage, would not be influenced by temperature. There can be no doubt that the electrostatic capacity of a cable as measured ballistically is open to grave possibilities of error on account of absorbed charge and by change of the absorption and insulation resistance with the temperature. In any event it is evident, from these and other considerations, that the so-called constants of resistivity and electric permitivity as usually determined in commercial cable testing are, in general, not to be taken as adequate for determining the actual voltage gradient in cables.

The authors of the paper under discussion have admirably assisted in opening the way to a wide field of investigation, speculation and practical application.

Wm. A. Del Mar (by letter): The following comments consist of two parts, (1) a discussion of the formula presented by Mr. Middleton, and (2) a discussion of the practical application of the theory of dielectric stresses to the determination of insulation thickness in ungraded cables.

1. Mr. Middleton's discussion of this paper has given rise to a question of the greatest importance, namely, the relation between the corona theory of stresses in dielectrics and the actual phenomena which occur in a stressed solid dielectric, and opinion being somewhat divided as to whether the insulation of a cable can be stressed to destruction internally without puncture, a brief survey of this subject will be attempted.

The authors of the paper under discussion give the following well known formula for the relation between the dielectric stress, the difference of potentials between conductor and sheath and the dimensions of the cable.

$$F = \frac{V}{\rho \ln \frac{R}{r}} \qquad (1)$$

where R = outer radius of insulation.

r = radius of conductor.

ρ = distance from axis of wire to point where dielectric stress is F, when the volts between wire and sheath equal V.

This formula is based upon the assumption that the lines of electrostatic induction extend radially between the conductor and sheath and that therefore their density, or, in other words,

the dielectric stress, is the greatest at the surface of the conductor, so that K, the maximum value of F is given by

$$K = \frac{V}{r \ln \frac{R}{r}} \tag{2}$$

If we keep the applied voltage and outside diameter of the insulation constant and vary the radius of the wire, we obtain

$$\frac{dK}{dr} = V \frac{\left(1 - \ln \frac{R}{r}\right)}{\left(r \ln \frac{R}{r}\right)^2} \tag{3}$$

An inspection of this equation tells us that if $\ln \frac{R}{r}$ is greater than one, $\frac{dK}{dr}$ will be negative, or, in other words, K will decrease as r increases. If we take into consideration the fact that $K = 4 \pi \epsilon$ times the number of lines of induction per square centimeter, a mental picture of the above relations may be obtained by resolving equation (2) into two parts as follows:

$$K = \frac{V}{2 \ln \frac{R}{r}} \times \frac{2}{r} \tag{4}$$

and dividing by $4 \pi \epsilon$ to obtain N the number of lines of induction per sq. centimeter at the surface of the conductor. Thus

$$N = \frac{V}{2 \ln \frac{R}{r}} \times \frac{2}{r} \times \frac{1}{4 \pi \epsilon}$$

$$= \frac{1}{2 \ln \frac{R}{r}} \times \frac{V}{\epsilon} \times \frac{1}{2 \pi r} \tag{5}$$

In this equation the first item represents the capacity of the condenser formed by the conductor and sheath; the product of the first and second terms represents the total number of lines of induction between the conductor and sheath; the third term is

reciprocal of the area per unit length of the conductor; and the product of the three terms, the number of lines of induction per sq. centimeter of conductor surface.

In Fig. A, curve B gives the relation between the total number of lines of induction between conductor and sheath and the conductor radius; curve C is the reciprocal of the conductor surface per unit length, and curve A is the number of lines of induction per unit area at the conductor surface, these curves being obtained from equation (5) as described above. It will be noted from Fig. A that curve A first drops owing to the slowness of the flux increase as compared with the rapidity of its surface attenuation and then rises again owing to the reversal of these conditions. There is therefore a point of minimum flux density and

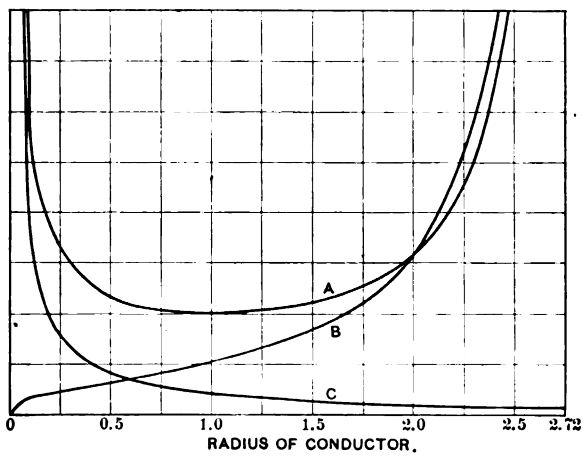


FIG. A.—Curve A: Dielectric stress, or lines of electrostatic induction per unit area. Curve B: Totol number of lines of electrostatic induction or condenser capacity. Curve C: Reciprocal of surface area per unit length

therefore of minimum dielectric stress and this occurs when r is $\frac{1}{2.72}$ of R.

The ordinates of these curves may be regarded either as flux densities or dielectric stresses, these quantities being related by a constant ratio. The ordinates are therefore given without any specified scale in order that the curves may be used for either of these quantities.

This graphical exposition is given in order to emphasize the physical meaning of the equations under discussion. Thus in the case of cables in which $\frac{R}{r}$ is greater than 2.72 we see

from curve A, Fig. A, that if the conductor were to grow in diameter, the dielectric stress at its surface would decrease until its diameter became $\frac{1}{2.72}$ of the outside diameter of the insulation, after which $\frac{R}{r}$ being no longer greater than 2.72 the stress would increase. If instead of the conductor growing in diameter, the dielectric at its surface were to break down, the effect would be the same. The stress in the uninjured dielectric where it meets the injured part would decrease until the diameter of the injured part equalled $\frac{1}{2.72}$ of the outside diameter of the insulation, after which the stress would decrease. If, therefore, the applied voltage is just sufficient to break down the layer of insulation nearest the conductors, the next layers of insulation will not necessarily break down, as the virtual increase of conductor diameter due to the breakdown of the layers will have eased the stress to a safe value. Hence in such a cable a partial internal distintegration of dielectric should be possible without a complete puncture.

Considering the case of cables in which $\frac{R}{r}$ is less than 2.72 so that K increases as r increases, a similar line of reasoning leads to the conclusion that if one layer of insulation is disrupted the next layer becomes more greatly stressed than the first and so on to the outside of the insulation, with the net result that the insulation is completely disrupted from the conductor to sheath.

Returning now to the consideration of cables wherein $\frac{R}{r}$ is greater than 2.72 and assuming that the disintegration of inner layers is unobjectionable if the outer layers remain intact, we come to the conclusion that the outside diameter of the insulation is a constant entirely independent of the size of conductor and dependent only on the applied voltage. Referring to equation (2) assume that $\frac{R}{r} = 2.72$ so that $r = \frac{R}{2.72}$ and $ln\ \frac{R}{r}$ becomes unity. Then

$$K = \frac{2.72\ V}{R}, \text{ or } R = \frac{2.72\ V}{K} \tag{6}$$

This is what Mr. W. I. Middleton's formula reduces to, when his wire diameter d is replaced by $\frac{D}{2.72}$ as he requires to be done.

Now it will be observed that the establishment of this formula depends upon the admission that the inner layers of insulation are broken down without injury to the outer layers; what, therefore, does Mr. Middleton mean by saying that "as far as Professor Russel's hypothesis that the dielectric near the conductor breaks down and becomes charred, is concerned, I do not believe it. In eight years in the testing room of a cable factory, I have never seen a cable that has shown mechanical change due to excess voltage in either rubber or cambric insulation." Granting that the insulation neither chars nor breaks down visibly it would be interesting to know, first, what kind of change actually occurred in the inner layers of those cables which he tested to check the accuracy of his formula, and second, is there any physical meaning to his formula if it does not assume the partial internal disintegration of the dielectric.

Without wishing in any way to deprecate the value of Mr. Middleton's work or question its originality, I must venture to observe that Professor Alexander Russel gives this formula in his paper read November 7, 1907, before the Institution of Electrical Engineers (JOURNAL I. E. E., Vol. 40, p. 15, line 12) but that Mr. Middleton deserves our thanks for calling attention to its practical value, especially to the fact that for a given voltage the outside diameter is a constant while the copper diameter is a reducible quantity.

. 2. The application of the theory of potential gradient to the practical design of ungraded cables is a matter of great importance to which we will now turn our attention.

The equation (2) may be reduced, for practical purposes, to the form

$$K = \frac{0.434\ V}{r \log \left(\frac{t+r}{r}\right)}$$

where the logarithm is to the base ten, and t represents the thickness of insulation. This equation may be used to calculate the thickness of insulation required to properly insulate a cylindrical wire of known radius. If, however, the wire is not cylindrical but consists of a strand of several wires, the formula becomes more complicated owing to the irregular distribution of the lines of induction about the wires composing the strand. It has been shown by Professor Levi-Civita that stranding has the effect of increasing the stress by a factor which varies from 1.23 for thick insulation, to 1.46 for thin insulation, an average value being 1.345, so that

$$K = \frac{0.585\ V}{\left(r \log \frac{t+r}{r}\right)} \tag{8}$$

The thickness of insulation calculated by the above formulæ is inadequate because there is always a certain amount of insulation which is not effective as such. In practical cable work, it is found necessary to add an extra thickness to make up for this inevitable deficiency. The useless thickness may be analyzed as follows.

1. Eccentricity of insulation about the wire making the insulation dielectrically stronger on one side of the wire than on the other, the excess on one side over that of the other being useless.

2. Insulation in immediate proximity to the wire being likely to be abraided in bending, etc., is rendered useless.

3. Insulation next to tapping being likely to contain depressions due to crinkling of tape is rendered useless.

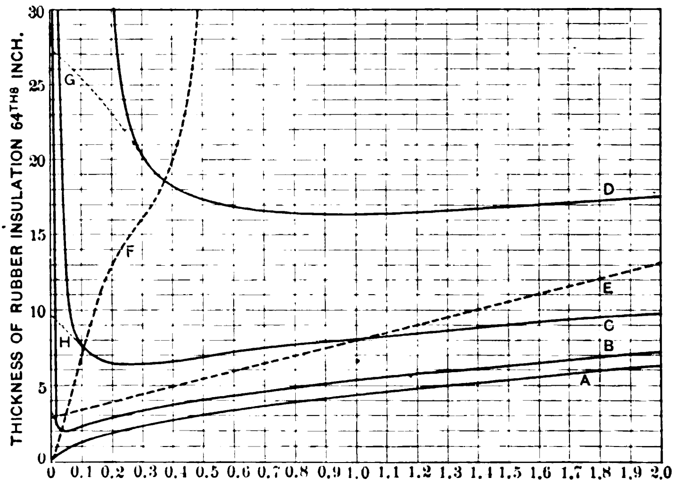


FIG. B

4. When cable is bent, the insulation on the outside of the bend is reduced. Hence, a cable when straight should have an excess of insulation in order that when bent, it may have just sufficient. This excess must, of course, be figured as useless in calculating insulation thickness on a straight conductor.

This "error thickness" as we may call the total of these quantities is a function of the size of conductor and has to be determined by experience. Curve *A* in Fig. B represents what the writer considers to be about the practical magnitude of the error thickness for rubber insulated cable.

Applying the logarithmic formula to the case of a wire insulated with rubber compound for 550 volts alternating current (or say 775 volts direct current) we obtain curve *B*, by assuming

a working stress of $K = 57$ kilovolts per inch and plotting the thickness obtained by calculation, upon curve *A* as base so that curve *B* represents the electrical thickness plus the error thickness. The thickness of insulation thus obtained is, however, not sufficient to meet the requirements of practical work owing to the severe mechanical stresses to which wires are subjected. It is therefore necessary to add insulation until the amount shown on curve *E* is reached.

Proceeding in the same way for 2300-volt cables, curve *C* is obtained, part of which is below and part above curve *E*. With wires for this voltage the thickness of insulation is therefore partly determined by mechanical and partly by electrical considerations.

Curve *D* is obtained in the same way for 6700-volt cables, this being used for 11,000 volts three-phase. This curve is entirely above curve *E*, showing that in this case, if sufficient rubber insulation is supplied to meet the electrical requirements, the cable will have ample mechanical strength.

Curve *F* is the result of Mr. W. I. Middleton's discussion. It is the line of demarcation between those combinations wherein $\frac{D}{d} > 2.72$ and those where $\frac{D}{d} < 2.72$. According to the theory reviewed above, curves *A*, *B*, *C* and *D* are worthless for all points on the left hand side of curve *F* and the special formula which applies to the values to the left of the curve *F* is shown graphically by curves *G*, *H* and *I*.

The curves *B*, *C*, *D*, *G*, *H* and *I* are based upon a working dielectric stress of 57 kilovolts per inch at the surface of the conductor, using the logarithmic formula modified to allow for the use of a stranded conductor instead of a perfectly cylindrical one. The stress of 57 kilovolts per inch allows a factor of safety of about seven, if an ultimate dielectric strength of 400 kilovolts per inch be assumed. This is about the same factor that is used in common structural design. The curves *A* and *E* are taken (by permission of the D. Van Nostrand Co.) from tables in Appendix III of the present writer's "Electric Power Conductors."

Engineers have hitherto avoided the use of small wires with heavy insulation because they cost more than larger wires with less insulation, and it is a curious fact that the curve *F*, which as explained above, has a purely physical basis, also represents, to a fair degree of approximation the limit of the commercial application of the old logarithmic law, *i.e.*, those portions of the curves *B*, *C* and *D* which are replaced by curves *I*, *H* and *G* respectively give thicknesses of rubber of insulation which are commercially impracticable. The curves *G*, *H* and *I*, may, on the contrary, give commercially practicable thicknesses of insulation and are therefore of more than academic interest, but at present prices ($0.14 per lb. for copper and $2.00 per lb. for

rubber) it is cheaper to use copper up to a diameter $\frac{1}{2.72}$ of the outside diameter than to use rubber compound on the expectation of its being disintegrated. In addition to this, the extra copper adds to the carrying capacity and to the scrap value, so that it is usually better engineering to use it instead of rubber.

The practical points brought out above in considering the thickness of ungraded insulation suggest that in designing graded insulation, the theory set forth by Messrs. Osborne and Pender may have to be materially modified in practical details before it can be adopted by the cable manufacturers.

H. S. Osborne: It has been pointed out in several of the discussions that the design curves which are given in the paper will be modified by mechanical considerations and by manufacturing conditions. The necessity, which Professor Kennelly points out, for good joints between the layers of insulation, in order that excessive local gradients will not appear at those joints, seems to have been met by cable manufacturers, if one may judge from the success of graded cables. That the design may also be influenced by other conditions is suggested by Dr. Steinmetz, whose remarks concerning the effect of transient voltages permit us to hope that he intends to shed some quantitative light on that subject. It is customary to consider that the electric strength of a dielectric depends upon the time duration of the impressed voltage; and it is probable that in designing a cable to withstand transient voltages, values for the electric strengths of the layers of insulation should be used which are quite different from the values determined by ordinary means. It does not appear, however, that the energy necessary to complete the breakdown of a dielectric, after it has been stressed up to the breaking point, would enter into the design of insulation, since the aim should usually be to keep the insulation from all overstress.

Mr. Rhodes has pointed out that the voltage which a cable can withstand is not necessarily the criterion by which it will be judged, and has very clearly shown what advantage may be expected from grading a cable when the aim is for a maximum safe kilowatt capacity per duct. In most cases the aim in designing a cable is for a minimum cost with fixed voltage and current-carrying requirements, and the design is therefore fixed by a consideration of relative costs, of which no analysis is attempted in this paper. In this connection it is interesting to hear from Mr. Middleton that cable manufacturers find grading to be of value for voltages above 15 kv., though theoretically the advantage to be gained depends, not on the voltage for which the cable is designed, but upon the ratio of that voltage to the diameter of the conductor.

It would seem to be a matter for personal preference to decide whether one shall express the stress on the dielectric in terms of

the electric flux density, as Mr. Fechheimer suggests, or in terms of the potential gradient. Personally, I prefer to consider the potential gradient to be the measure of the electric stress to which the dielectric is subjected, and the flux density to be the measure of the resulting strain. It is advantageous to deal with what is, from this point of view, the stress, rather than to deal with the strain, because a potential gradient is more easily measured than a flux density, and the electric strengths of dielectrics are ordinarily given in terms of potential gradient. The characteristic of a dielectric which is of primary interest is its volt-resisting ability, rather than its ability to transmit electric flux.

In remarking that "electric strengths are limited at present, in the manufacture of cables, to a very few values," the authors did not mean to convey the idea that electric strengths are limited to a single value. The criterion given by Mr. Fechheimer for the ideal grading of cables is expressed in equation 5 of the paper.

Mr. Rhodes and Mr. Waring have discussed the effect of a temperature gradient in the insulation of a cable on the distribution of the electric stress. Mr. Höchstädter, to whose recent researches Mr. Waring refers, found that not only the effective capacity of an impregnated paper cable, but also what he calls the "true" capacity of the cable remained sensibly constant for temperatures between 20 deg. and 60 deg. cent., though the "static" capacity, as measured by a ballistic galvanometer, increased largely. It seems probable, then, that the effect of temperature gradient in equalizing the stress in a cable is very small, if it is indeed appreciable.

The conclusion in the paper with regard to the nature of partial breakdown in solids seems to be generally acceptable; Dr. Steinmetz, indeed, considers it to be a fairly well known fact. It is so simple and obvious an explanation of experimental results that it would be remarkable if some such idea had not been in the minds of some engineers, but it has not before, as far as I am aware, been expressed in public discussions of this subject.

In describing in terms of the electron theory the experiments reported in the paper, Professor Whitehead seems to be mistaken with regard to one of the experimental facts. The experiments in no case indicated that the dielectric could be overstressed without breakdown, but in each case the dielectric broke down when its electric strength was exceeded. Dr. Steinmetz's experiments lead him to conclude, however, that under certain circumstances the electric strength of a dielectric may be exceeded without causing any change in the material.

Mr. Thomas describes the experimental results in terms of local heating. In adopting this point of view one should bear in mind the fact that the "heating" seems to be of a different sort from that due to ohmic resistance, and is accompanied by a

disintegration of the material at the point of puncture, however small may be the current which is allowed to flow. In the cases in which the authors have observed the melting and pitting of a dielectric before puncture which was remarked by Mr. Mailloux in substances of low melting point, the heating has evidently been caused by the brush discharge in the air around the electrodes.

Mr. Fisher and Mr. Thomas have both suggested that the experimental results observed would be different, or at least less pronounced, were materials other than glass and rubber used for the experiments. This may well be, and it is to be hoped that experiments will soon be forthcoming which will more completely determine the behavior of overstressed dielectrics. It does not seem probable that the *character* of the partial breakdown was due to the presence of flaws in, or to the lack of homogeneity of the material, as suggested by Professor Whitehead and Mr. Franklin, though doubtless the voltage at which that breakdown occurred was influenced by the lack of absolute homogeneity. The possible effect of a layer of air, suggested by Professor Kennelly and Mr. Thomas, was obviated after the earliest experiments by the use of a liquid dielectric between the rubber and the glass tube.

The curves marked C in Figs. 10 and 12 were intended only to give a very rough idea of the magnitude of charging current which might be expected in those cases of partial breakdown. As the resistance to the passage of current along the lines of incipient disruption is probably low, the change in the phase angle of the current which is suggested by Mr. Atkinson does not necessarily occur, and it was therefore assumed in computing curves C that the phase angle of the current remained unchanged. The increase in " static " capacity which was noted by Professor Kennelly in the testing of some rubber cable would seem to be most readily explained by a rise in the temperature of the dielectric.

It is very interesting to learn from Mr. Middleton that the formula which assumes the complete breakdown of the overstressed zone of a thick wall of insulation gives results which are satisfactory in practice. This fact seems to indicate that in the cases with which Mr. Middleton deals the potential gradient remaining in the partially disrupted zone of insulation approximately compensates for the excessive stresses introduced by the needlepoints.

The inconsistency of the present nomenclature concerning capacity prompts one to wish that the term *permittivity*, which Mr. Waring uses, might come into general use. If Heaviside's rational units were adopted the nomenclature could be simplified in the way indicated in the following. For the sake of simplicity, the case here considered is that of a parallel plate condenser, A representing the effective area of the plates and t the thickness of the dielectric:

Quantity	Present name	Rational name
$\frac{\epsilon A}{t}$	Capacity	Permittance
ϵ	Specific capacity	Permittancy or permittivity

There seems to be little hope of the immediate adoption of a rational system of electric units, but with our present system of units the capacity nomenclature could be made consistent with the rest of electrical nomenclature. For example, the following terms have been suggested:

Quantity	Present name	Consistent name
$\frac{\epsilon A}{4 \pi t}$	Capacity	Capacitance
$\frac{\epsilon}{4 \pi}$	(?)	Capacity, or capacitivity
ϵ	Specific capacity	Permittivity

Harold Pender: I wish to take this opportunity to state that the theoretical investigations and experimental work described in the paper under discussion were carried out almost entirely by Mr. Osborne himself. In fact, Mr. Osborne had completed the mathematical investigation of the subject before I had the pleasure of making his acquaintance. My part in the work was solely of an advisory nature. Mr. Osborne undertook the investigation at the suggestion of Professor H. E. Clifford and completed it under my direction.

THE ELECTRICAL CONDUCTIVITY OF COMMERCIAL COPPER*

BY F. A. WOLFF AND J. H. DELLINGER

I. Introduction

The values in use for the conductivity, resistivity, and temperature coefficient of copper vary considerably. The standard values for annealed copper as used by various institutions in different countries are given in the following table.

2. NOTES ON TABLE OF STANDARD VALUES

The values given in the table for the various temperatures are computed from the values at the particular standard temperature, which are indicated by heavy-faced type. In each column, the temperature coefficient of that column is used in computing the resistivity in ohms per meter-gram at the various temperatures.

The data for the English values (column 1) were obtained from the report of the Engineering Standards Committee, August, 1904.

The values for " Normal Kupfer " (column 2) were computed from the data given in Elek. Z. S. 17, 402; 1896, and " Normalien, etc. d Verbandes Deutscher Elektrotechniker ", 1907, page 68. The value for conductivity given was reduced to meter-gram resistivity by the use of the density given as standard, 8.91. The values in column 3 are calculated on the assumption of a density of 8.89. The German " Normal Kupfer " is in use also in Austria.

The Matthiessen value as computed by Lindeck (column 4) is based on the data given in C. Hering's " Conversion Tables " (John Wiley and Sons, N. Y., 1904), page 104, and was reduced

* Abstract of a paper to appear in Bulletin of the Bureau of Standards, Vol. 7.

to the meter-gram basis on the assumption of the density, 8.89, and Matthiessen's temperature formula.

The values which were adopted by the American Institute of Electrical Engineers in 1893 are given in column 5. They were derived from the results Matthiessen published in 1862. (The 0 deg. and 20 deg. meter-gram values are equivalent to 1.59425 and 1.72128 micro-ohms per cm. cube, respectively). In 1908, Matthiessen's temperature formula was dropped by the A.I.E.E. and the linear temperature coefficient of 0.0042 at 0 deg. cent. was adopted (column 6); this vitiated the old wire table of the Institute; and, as the 0 deg. value of the resistivity at all other temperatures was retained, the resistivity at all other temperatures was altered. The 20 deg. value of the resistivity was retained by the Bureau of Standards (since the measurements of Matthiessen at 20 deg. cent were probably at least as reliable as those at lower temperatures, and since the 20 deg. value was the one in practical use even on the old basis), and the temperature coefficient of 0.0042 at 0 deg. cent was adopted, (column 7).

Since a more accurate value for the temperature coefficient has been obtained at the Bureau of Standard, it has been applied to give the values in column 8, which represent the present practice of the Bureau.

3. SCOPE OF THIS INVESTIGATION

The foregoing table makes evident the need for data to be used in establishing more reliable standard values. The matter of obtaining such data having been submitted to the Bureau of Standards by the American Institute of Electrical Engineers, an investigation has been made of the copper furnished for electrical uses. The coöperation of a number of the important refiners and manufacturers of copper wire was secured. These companies furnished samples for measurement, and information regarding their material and their practices. Incidental to the investigation of copper, it was thought desirable to secure some data on aluminum; and, accordingly, the coöperation of the chief producer of aluminum was also secured. The companies whose material was represented in the investigation were the following:

Smelters.	Calumet and Hecla Smelting Works, Hubbell, Mich. Quincy Mining Company, Hancock, Mich. Buffalo Smelting Works, Buffalo, N. Y.
Electrolytic Refiners.	American Smelting and Refining Co., Maurer, N. J. The Baltimore Copper Smelting and Rolling Co., Baltimore, Md. The U. S. Metals Refining Co., Chrome, N. J. Raritan Copper Works, Perth Amboy, N. J. Nichols Copper Co., Laurel Hill, N. J. A. Grammont, Pont-de-Cheruy, France.

Wire Manufacturers.	American Brass Co., Waterbury, Conn. John A. Roebling's Sons Co., Trenton, N. J. Standard Underground Cable Co., Perth Amboy, N. J. Heddernheimer Kupferwerk und Suddeutsche Kabelwerke, Frankfurt-am-Main, Germany. Kabelfabrik-und Drahtindustrie-Actien-Gesellschaft, Vienna, Austria
Aluminum Wire Manufacturer.	Aluminum Company of America, Pittsburg, Pa.

Eleven of these companies kindly furnished samples and information at the request of the Bureau of Standards, and the Bureau desires hereby to express its thanks and appreciation for their assistance. Samples of the products of the other four companies were obtained in other ways. Particular thanks is due Mr. W. H. Bassett, of the American Brass Company, who has taken great interest in the work, and who has contributed a valuable set of data on conductivity; and to Mr. Wm. Hoopes, of the Aluminum Company of America, who furnished valuable data on aluminum; and to Mr. E. A. C. Smith, of the Baltimore Copper Smelting and Rolling Company, who supplied valuable information and a quantity of specially refined cathode copper. The authors desire also to express their appreciation of the assistance of Mr. E. E. Weibel, who made some of the measurements.

A considerable number of the most important refiners and manufacturers of copper wire in this country are included in the above list; Germany, France and Austria are each represented by one company. Since most of the world's copper is refined in this country, and the results of the measurements on the foreign samples showed no particular difference from the American samples, all the results will be given without distinguishing the foreign from the American product. The various companies were asked to furnish representative samples of their regular commercial product, both hard-drawn and annealed, and from two to twenty samples were received from each. It is not believed that the measurements made upon the few samples from each company indicate accurately the average of the product of that company, but it is considered that the mean of all the measurements indicates very well the average of the present copper of commerce. The results are given below. Results are also given for measurements on a few aluminum wires, together with the data on aluminum furnished by the Aluminum Company of America.

An effort was also made to determine what was the highest conductivity obtainable without extraordinary experimental precautions and expense, and the measurements made upon a

few samples of copper of especially high conductivity are, therefore, also given. It was considered desirable also to make a complete investigation of the effect upon the conductivity of drawing to progressively smaller sizes, and to study the question of annealing, but these two matters have had to be dropped because of the pressure of other work; it is hoped that they can be taken up at a later time.

II. The Experimental Work

The samples upon which measurements were made were wires Nos. 6 to 18, B. & S. gauge, about 120 cm. in length. Most of the samples were No. 12. The resistivity in ohms per meter-gram and per cent conductivity were computed from measurements of the length, mass and resistance. The resistivity in ohms per meter-gram is the product of the resistance per meter and the mass per meter. The per cent conductivity is computed by dividing 0.153022 by the resistance per meter-gram at 20 deg. cent. (This figure is the value assumed by the Bureau of Standards as representing the " Matthiessen Standard " at 20 deg. cent. It corresponds to 1.72128 micro-ohms per centimeter cube at 20 deg. cent., on an assumed density of 8.89). The Thomson bridge method was used for measuring the resistances, and an accuracy of 0.01 per cent was easily attained. The resistance of the copper sample was compared with the resistance of a copper standard in the same bath as the test sample, thus eliminating the necessity of very accurate temperature measurement. The resistances of the copper standards were carefully checked from time to time against manganin standards; in these measurements, of course, temperature as well as resistance had to be measured accurately. The accuracy of the resistivity and conductivity values obtained is believed to be within 0.03 per cent, a limit determined chiefly by the uncertainty of the total length measurement (many of the wires were not entirely free from small bends), and the lack of uniformity of cross-section of the wires.

[The Thomson bridge method and the apparatus are described Parts II and III of the original paper. Also, the results obtained are given in detail. We pass on here to the discussion of results.]

IV. Discussion of Results

1. Annealed Copper Wires

(*a*) *Summary of above data.*—It was found that annealed copper wires did not differ in conductivity with the size of wire.

TABLE I

STANDARD VALUES FOR THE RESISTIVITY, TEMPERATURE COEFFICIENT, AND DENSITY OF ANNEALED COPPER

Temperature *C*	**1** England (Eng. Stds. Com. 1904)	**2** Germany "Normal Kupfer" density 8.91	**3** Germany "Normal Kupfer" assuming density 8.89	**4** Lindeck Matthiessen value assuming density 8.89	**5** A.I.E.E. Before 1908 (Matthiessen value)	**6** A.I.E.E. after 1908	**7** Bureau of Standards Before July 1, 1910	**8** Bureau of Standards After July 1, 1910
	Resistivity in ohms per meter-gram.							
0°	0.14136_2	0.13959_0	0.13927_7	0.14157_1	$\mathbf{0.14172_9}$	$\mathbf{0.14172_9}$	0.14116_4	0.14106_8
15°	0.15043_7	$\mathbf{0.14850_0}$	$\mathbf{0.14816_7}$	$\mathbf{0.14997_4}$	0.15014_1	0.15065_8	0.15005_8	0.15003_4
(15.6°)	**0.1508**							
20°	0.15346_3	0.15147_0	0.15113_0	0.15285_1	0.15302_2	0.15363_4	$\mathbf{0.15302_2}$	$\mathbf{0.15302_2}$
25°	0.15648_8	0.15444_0	0.15409_3	0.15576_5	0.15593_8	0.15661_0	0.15598_6	0.15601_0
	Temperature Coefficient.							
0°	**0.00428**	$\mathbf{0.00425_5}$	0.00425_5	Matthiessen's formula	Matthiessen's formula	**0.0042**	**0.0042**	[1](0.00427_7)
15°	0.00402_2	**0.004**	**0.004**			0.00395_1	0.00395_1	[1](0.00401_9)
20°	0.00394_3	0.00392_2	0.00392_2			0.00387_5	0.00387_5	[1](**0.00394**)
25°	0.00386_6	0.00384_6	0.00384_6			0.00380_1	0.00380_1	[1](0.00386_4)
	Density							
	8.89	8.91	(8.89)	(8.89)	8.89	8.89	8.89	8.89

1. This temperature coefficient applies only to this particular resistivity. The temperature coefficient is considered to be proportional to conductivity. Expressed otherwise, the change of *resistivity* per degree cent. is considered to be a constant, viz., **0.000598** ohm per meter-gram.

For 89 annealed samples from 14 important producers the mean results were:

Resistivity in ohms per meter-gram at 20 deg. cent.. =	0.15292
Per cent conductivity........................... =	100.07

The average deviation from these means was 0.26 per cent, and the maximum deviation of any group was 0.81 per cent. The general agreement of the results indicates that the refiners are producing copper very satisfactory in its uniformity of quality.

(*b*) *Summary of data from American Brass Company.* We present here also the results of the data collected by the American Brass Company, which were furnished by Mr. W. H. Bassett, and which are given with his permission. Measurements were made upon annealed No. 12 samples, at least one sample from each carload of wire bars. The wire bars represented a number of the important refiners of copper. Practically all the material had been electrolytically refined. For samples from more than 2000 carloads, or more than 100,000,000 lb., of wire bar copper:

Mean resistance per meter-gram at 20 deg. cent.... =	0.15263
Mean per cent conductivity...................... =	100.25

This result is regarded as reliable, as the work of this laboratory is known to be done with care, and as its standards for conductivity measurements are in agreement with those of the Bureau of Standards. This result is much more representative, in pounds of copper, than the result just given above. The fact that the value for conductivity is higher is corroborative of the former result, because this company (like others who make conductivity tests) accepts only copper of the higher conductivity.

It is to be observed that both the mean values as found in this investigation, and as found by Mr. Bassett, for the mean resistivity and per cent conductivity differ from the standard values (0.153022 and 100 per cent) by less than 0.26 per cent, which is the above average deviation from the mean. It is interesting that the standard values, derived from the experiments of fifty years ago on copper supposed to be chemically pure, are so close to the average of commercial copper to-day. It at once suggests itself that the present standard of resistivity is a good one to retain for commercial copper.

2. HARD-DRAWN COPPER WIRES

The results on the hard-drawn wires may best be summarized by considering the difference in conductivity between annealed and hard-drawn samples. It was found that this difference in conductivity varies with the size of the wire. Most of the wires used were No. 12 B. & S., and for that size *the conductivity of annealed wires was found to be greater than the conductivity of hard-drawn wires by* 2.7 per cent.

Only a few No. 6 and No. 18 wires were experimented upon, and the mean results are stated above. The values are not considered as having much weight, being based on such limited experimental evidence; but they show, as was to be expected, that the difference between the conductivity of annealed and hard-drawn wires increases as the diameter of the wire decreases. This general conclusion is, however, complicated in any particular case by the particular practice of the wire drawer, in regard to the number of annealings between drawings, amount of reduction to each drawing, etc.

3. THE HIGHEST CONDUCTIVITY FOUND

The lowest resistivity and highest conductivity found, for a *hard-drawn* wire, were:

Resistivity in ohms per meter-gram at 20 deg. cent. . =	0.15386
Per cent conductivity . . . . =	99.46

and for an annealed wire, were:

Resistivity in ohms per meter-gram at 20 deg. cent. . =	0.15045
Per cent conductivity . . . . =	101.71

The former wire was drawn from a cathode plate without melting. The latter wire was drawn directly from a mass of native lake copper which had never been melted down.

4. ALUMINUM

Data on the conductivity of hard-drawn aluminum is given. For seven samples of commercial aluminum, supposed to be fairly representative of the present output of the Aluminum Company of America, the mean results were:

Resistivity in ohms per meter-gram at 20 deg. cent . =	0.07573
Resistivity in micro-ohms per centimeter cube at 20 deg. cent. . . . . =	2.8060
Density . . . . =	2.699

The chemical analysis of these wires is also given. The mean resistivity of the company's output of all sizes of wire for the past five years was furnished by the company. The value was given by the company in terms of the resistance per centimeter cube, and has been reduced to the meter-gram basis by the use of the density just stated. The values are:

Resistivity in ohms per meter-gram at 20 deg. cent.. =	0.07633
Resistivity in micro-ohms per cm. cube at 20 deg. cent. =	2.8283
Per cent conductivity on cm. cube basis =	60.86%
Per cent conductivity on meter-gram basis =	200.46%

This result is considered to be a very good average value for commercial hard-drawn aluminum. It is, of course, entitled to much greater consideration than the above results on seven samples.

Aluminum wire is always furnished hard-drawn, hence no data is given on annealed samples.

5. TEMPERATURE COEFFICIENT OF COPPER

The work on the temperature coefficient, reported in the paper on "The Temperature Coefficient of Resistance of Copper".[3] was done upon samples included in this investigation.

V. CONCLUSIONS

1. BEST VALUE FOR THE RESISTIVITY OF ANNEALED COPPER

The mean value found for the 20 deg. cent. resistivity of commercial annealed copper is very close to the standard value previously assumed by the Bureau of Standards, and by the American Institute of Electrical Engineers before 1908. We are accordingly led to the conclusion that the best value to be assumed for the resistivity of annealed copper, in the preparation of wire tables and in the expression of per cent conductivity, etc., is said standard value, *viz.*:

0.153022 ohm per meter-gram at 20 deg. cent.

Thus, three of the standard 20 deg. cent. values in Table 1, page 1985, are in agreement. The standard values at other temperatures, however, are not in agreement because of differences in the temperature coefficient assumed. Applying the

[3] Bulletin of the Bureau of Standards, Vol. 7, 1910, PROCEEDINGS A.I.E.E., December 1910, page 1995.

temperature coefficient which is discussed above, and which is equivalent to a change of resistivity per degree cent.

$$= 0.000598 \text{ ohm per meter-gram},$$

we obtain the following values of the standard resistivity at various temperatures:

Temperature Centigrade	Resistivity in ohms per meter-gram
0 deg.	0.1411
15 "	0.1500
20 "	0.153022
25 "	0.1560

It will be noticed that the value, 0.15 at 15 deg. cent., is a round number easily remembered, and happens to agree with the 15 deg. cent. value of the Matthiessen Standard as computed by Lindeck (column 4, Table 1). It is proposed that the resistivity represented by the foregoing values be called the "***Annealed Copper Standard***". (The term "Matthiessen Standard" has been applied to too many different values to be considered).

2. DENSITY OF COPPER

When it is desired to calculate the resistance of wires from dimensions, it is necessary that a density be given, as well as the meter-gram resistivity. *It is proposed that the standard density for copper, at* 20 *deg. cent. be taken as* 8.89. This is the value which has been used by the A.I.E.E., and most other authorities. Measurements made on a number of the samples in this investigation indicated this value as a mean. This density, 8.89, at 20 deg. cent, corresponds to a density of 8.90 at 0 deg. cent. Applying the above values of density and of meter-gram resistivity, the resistivity of the "Annealed Copper Standard" is found to be equivalent to a specific resistance of 1.72128 microhms per centimeter cube at 20 deg. cent. or a specific conductivity of 5.8096 (10^{-4}) c.g.s. units at 20 deg. cent.

3. TEMPERATURE COEFFICIENT OF ANNEALED AND OF HARD-DRAWN COPPER

According to the discussion of the temperature coefficient, page 1995, it is proposed that, in cases where assumption is unavoidable, the temperature coefficient of good commercial *annealed* copper wire be assumed as:

$\alpha_0 = 0.00428$, $\alpha_{15} = 0.00402$, $\alpha_{20} = 0.00394$, $\alpha_{25} = 0.00386$, and that the temperature coefficient of good commercial *hard-drawn* copper wire be assumed as:

$$\alpha_0 = 0.00415, \alpha_{15} = 0.00391, \alpha_{20} = 0.00383, \alpha_{25} = 0.00376.$$

4. PER CENT CONDUCTIVITY

Per cent conductivity may be calculated by dividing the resistivity of the Annealed Copper Standard, at 20 deg. cent. by the resistivity of the sample as 20 deg. cent. Inasmuch as the temperature coefficient of copper varies with the conductivity, it is to be noted that a different value will be found if the resistivity at some other temperature is used. This difference is of practical moment in some cases. For example, suppose the resistivity of a sample of copper is 0.1594 at 20 deg. cent; dividing 0.1530 by this, the per cent conductivity is 96 per cent. Now the corresponding 0 deg. cent. resistivity of the sample is 0.1474; dividing 0.1411 by this, the per cent conductivity is calculated to be 95.7 per cent. In order that such differences shall not arise, it is suggested that the 20 deg. cent. value of resistivity always be used in computing the per cent conductivity of copper. When the resistivity of the sample is known at some other temperature, *t*, it is very simply reduced to 20 deg. cent. by adding the quantity, $(20 - t)$ multiplied by 0.000598 ohm per meter-gram.

5. DATA FOR USE IN WIRE TABLES

The data available from this investigation for use in connection with the preparation of wire tables are, in addition to the foregoing values for (1) the resistivity and (2) the temperature coefficient of copper, the following: (3) the difference, 2.7 per cent, between the conductivity of annealed and hard-drawn No. 12 copper wire, together with a recognition of the general increase of this difference as the diameter of the wire decreases; (4) data on commercial hard-drawn aluminum, as follows:

ALUMINUM

Resistivity in ohms per meter-gram at 20 deg. cent..	=	0.0763
Micro-ohms per cm. cube at 20 deg. cent.........	=	2.828
Density....................................	=	2.70

6. THE EXPRESSION OF RESISTIVITY IN OHMS PER METER-GRAM

The advantages of the expression of resistivity in terms of ohms per meter-gram may well be emphasized here. In specifi-

cations for purchase, or in expressing the results of conductivity measurements, the statement of the meter-gram resistivity avoids all questions of standard values which arise in connection with the per cent conductivity. The use of the meter-gram basis corresponds most closely to the usual methods of making conductivity measurements in practice. There are cases, however, in which the cross-section is measured and not the mass, and hence the centimeter-cube resistivity obtained. The difficulty of expression in terms of per cent conductivity at once arises, that per cent conductivity can be computed either from the meter-gram resistivity or the centimeter cube resistivity. If the density of the sample differs from the standard density, these two per cent conductivities will not agree. This difficulty is made particularly clear by an inspection of the data on aluminum given above. The extreme difference between the per cent conductivities on the two bases makes manifest the absurdity of the extension of the idea of per cent conductivity to metals of different density from that of copper, *unless* it be stated upon which basis the per cent conductivity is reckoned. Thus, we may speak of the " per cent conductivity on the meter-gram basis, per cent conductivity on the centimeter cube " basis. It is suggested that these terms be shortened, respectively, to the " mass per cent conductivity " and the " volume per cent conductivity ", which terms should be readily understood. The various sources of possible confusion in the use of per cent conductivity make it desirable that the actual resistivity be stated. The meter-gram resistivity is preferable to the centimeter cube resistivity, because (1) *the measurement of cross-section in many cases is difficult and inaccurate.* (2) *the direct measurement of cross-section is practically impossible for irregular shapes of cross-section.* (3) *copper is sold by weight rather than by volume, and therefore the data of value to most users is given directly by the meter-gram resistivity.*

7. DESIRABILITY OF AN INTERNATIONAL STANDARD OF COPPER CONDUCTIVITY

It is desired that the foregoing data and suggestions shall not confuse existing practice, and it is not expected that they will make any change in the electrical engineering practice of this country until taken cognizance of by the American Institute of Electrical Engineers. Furthermore, an international agreement on copper standards is considered desirable. To ascertain

whether this might be possible, the Bureau of Standards has had some preliminary correspondence with the national laboratories of Germany, England, France and Austria. Considerable interest was manifested in the matter. The use of the meter-gram basis was looked on with favor. In Germany and England the matter was referred to the national electrical engineering societies. No definite consideration has been as yet given by these bodies to the matter of international copper standards. Particularly in view of the fact that the vast bulk of the world's copper is mined and refined in the United States, it would seem appropriate for the American Institute of Electrical Engineers, through the International Electrotechnical Commission, to lead an attempt to secure agreement among the various engineering bodies. It is desired that none of the proposals in this paper should stand in the way of such an international agreement. It might seem desirable to base the international standard resistivity upon the purest copper that can be produced, instead of upon such an average of the commercial product as is given in this paper. However, difficulties arise in that direction. Finally, it is believed that the expression of conductivity on a percentage basis will be thoroughly satisfactory only after a definite international standard has been established.

VI. Summary

1. The various standard values in use for the resistivity and temperature coefficient of copper are given, and the need for the present investigation shown.

2. The means of making precise measurements of conductivity of wire samples is described.

3. The resistivities are given for 89 samples of commercial copper from 14 important refiners and wire manufacturers in this and other countries. The mean for annealed wires is:

Resistivity in ohms per meter-gram at 20 deg. cent.. =	0.15292
Per cent conductivity.......................... =	100.07

(Per cent conductivity is computed on the basis of 100 per cent conductivity corresponding to the standard resistivity, 0.153022 ohm per meter-gram at 20 deg. cent.). The mean result of data furnished by a large wire manufacturing company, representing tests on more than 100,000,000 pounds of copper, is also given, *viz.*, for annealed samples:

Resistivity in ohms per meter-gram at 20 deg. cent.. =	0.15263
Per cent conductivity.......................... =	100.25

It is concluded that the best value to be assumed for the resistivity of *annealed* copper, in the preparation of wire tables and in the expression of per cent conductivity, etc., is the previously used standard value, *viz.*:

0.153022 ohm per meter-gram at 20 deg. cent.

4. The conductivity of hard-drawn No. 12 B. & S. wires was found to be less than the conductivity of annealed wires by a mean value of 2.7 per cent. The difference between the conductivity of annealed and hard-drawn wires increases as the diameter of the wire decreases.

5. The lowest resistivity and highest conductivity found, for a *hard-drawn* wire, were:

Resistivity in ohms per meter-gram at 20 deg. cent.. =	0.15386
Per cent conductivity........................... =	99.46

and for an *annealed* wire, were:

Resistivity in ohms per meter-gram at 20 deg. cent.. =	0.15045
Per cent conductivity........................... =	101.71

6. Representative mean values for commercial hard-drawn aluminum were obtained, as follows:

Resistivity in ohms per meter-gram at 20 deg. cent.. =	0.0763
Resistivity in micro-ohms per cm. cube at 20 deg. cent.................................... =	2.828
Density.................................... =	2.70

7. The work on the temperature coefficient of resistance of copper, which is reported in another paper,[4] was done upon samples included in this investigation. The temperature coefficient was found to be substantially proportional to the conductivity. This relation may be expressed thus: the change of *resistivity* per degree cent. is a constant for copper, independent of the temperature of reference and independent of the sample of copper; this constant is:

0.000598 ohm per meter-gram.

8. The advantages of the expression of resistivity in ohms per meter-gram are stated.

9. The desirability of an international standard of copper conductivity is urged.

[4] Bulletin of the Bureau of Standards, Vol. 7, 1910; PROCEEDINGS A.I.E.E., December, 1910, page 1995.

THE TEMPERATURE COEFFICIENT OF RESISTANCE OF COPPER*

BY J. H. DELLINGER

INTRODUCTION

1. FORMER VALUES IN USE

Widely varying values are in use for the temperature coefficient of resistance of copper. Some of those which have been much used are given in the following table, in which α_0 and α_{20} are given respectively by the equations:

$$R_t = R_0\,(1+\alpha_0\,t) \qquad\qquad R_t = R_{20}\,(1+\alpha_{20}\,([t-20])$$

R_0, R_{20}, R_t = resistance respectively at 0 deg. cent, at 20 deg. cent, and at t deg. t = any temperature centigrade.

	α_0	α_{20}
Matthiessen's temperature coefficient, 0 deg. cent. to 20 deg. cent.	0.00398	0.00369
Laboratoire Central d'Electricite	0.00400	0.00370
Kennelly and Fessenden, 1890	0.00406	0.00375
American Institute of Electrical Engineers	0.00420	0.00387
Verbano Deutscher Elektrotechniker	0.00426	0.00392
(British) Institution of Electrical Engineers	0.00428	0.00394
Lagarde, 1893	0.00445	0.00409

Matthiessen's formula is: $\lambda_t = \lambda_0\,(1 - 0.0038701\,t + 0.000009009\,t^2)$. λ_t and λ_0 = conductivity, or reciprocal of resistance, at t deg. and 0 deg. cent, respectively.

The second value given is that used by French engineers. The value given by the American Institute of Electrical Engineers

* Abstract of a paper to appear in Bulletin of the Bureau of Standards, Vol. 7. Copies of the complete paper may be obtained upon request, by addressing "Bureau of Standards, Washington, D. C."

has also been assumed by the Bureau of Standards. The value given by the Verband Deutscher Elektrotechniker has been in general use in Germany since 1896, and was obtained by assuming $\alpha_{15} = 0.004$. The relations between α_0, α_{15}, etc., are given in the appendix of this paper. The British Institution of Electrical Engineers' value is based on the results of Clark, Ford, and Taylor, in 1899, and happened to be the same as that determined by Dewar and Fleming in 1893. Matthiessen's two-term formula, published in 1862, is given in terms of conductivity instead of resistance, and has been used probably more than any other. Inasmuch as a linear formula suffices to express the accuracy of all work done up to the present for moderate temperature ranges, and as the many digits of Matthiessen's coefficients are without significance (the first being the mean of a number of values ranging from 0.0037351 to 0.0039954), it is evident that the further use of this formula is undesirable.

2. NECESSITY FOR THE PRESENT INVESTIGATION

The variations of the values in the above table may be considered to be due either to errors of the measurements made in establishing them or to differences in the temperature coefficients of different samples of copper. In either case, accurate results can not be expected when one of these values is taken as fixed and used for all samples. That this fact is not recognized is shown by the common practice of assuming that the temperature coefficient is the same for different samples of copper, while the conductivity is usually measured. It was accordingly considered of importance to determine whether the temperature coefficient of different samples does vary, and also to find whether there is any simple relation between the conductivity and the temperature coefficient.

An investigation has been carried out with the above in view upon samples of copper which represent a considerable number of the chief sources of supply of the copper used for electrical purposes and which include the native metal, that refined by smelting, and that refined by electrolysis. The results show that there are variations of the temperature coefficient, and that to a fair accuracy the relation of conductivity to temperature coefficient is a simple proportionality. This relation is in corroboration of the results of Matthiessen and others for differences in conductivity caused by chemical differences in samples; but the present results show that it holds for both physical and

chemical differences. Thus, hard-drawing and annealing, even more exactly than changes in chemical composition, cause proportional changes in conductivity and temperature coefficient.

II. Experimental Data

The experimental work was carried out with wires, sizes 6 to 12, Brown & Sharpe gage, of about 120 cm. length. The resistivity and per cent conductivity were computed from measurements of the length, mass, and resistance. The resistivity is given in ohms per meter-gram by multiplying the resistance per meter by the mass per meter. The " per cent conductivity " is calculated on the assumption of 100 per cent conductivity corresponding to a resistivity of 0.153022 ohm per meter-gram at 20 deg. cent.[1] According to practice that is now very general in scientific work, 20 deg. cent is used as the standard temperature instead of 0 deg. cent. The final results will be given, however, for 0 deg. cent., 15 deg. cent., 20 deg. cent., and 25 deg. cent., and they can be computed for any temperature.

1. The Resistance Measurements

For the resistance measurements the wires were placed in a specially designed oil bath with provisions for efficient stirring of the oil, for heating and cooling, and for temperature regulation. The wire was held between heavy clamps through which the current was introduced. For conductivity determinations the resistance was measured between knife edges mounted one meter apart on the marble base. The Thomson bridge method was used for measuring the resistances, employing a double set of variable ratio coils; an accuracy of 1 in 10,000 was easily attained. The resistance of the copper sample was compared with the resistance of a copper standard in the same bath as the test sample. The copper standards were wires carrying soldered potential leads and placed in frames having connections for both current and potential leads. These connections dropped into mercury cups on the marble base in the oil bath. The resistances of the copper standards were compared from time to time with manganin resistance standards which were kept in a separate oil bath. The method of comparing the copper samples

1. This is the value assumed by the Bureau of Standards as representing " Matthiessen's standard," an arbitrary standard in wide use commercially. This value corresponds also to 1.72128 micro-ohms per centimeter cube at 20 deg. cent. on an assumed density of 8.89.

with a copper standard has the advantage that accurate temperature measurement is unnecessary.

2. THE TEMPERATURE COEFFICIENT MEASUREMENTS

For the measurements of the temperature coefficient, potential terminals were used. The resulting temperature coefficient is therefore that of "constant mass." The temperature coefficient was measured by comparing the resistance of the sample as two or more temperatures with the resistance of a copper standard in the same bath. Temperatures were measured with a mercury-in-glass thermometer. The accuracy of the temperature coefficient values is estimated as within 0.000004, or 0.1 per cent. To an accuracy of 0.2 per cent, the temperature coefficient was found to be linear between 10 deg. cent. and 100 deg. cent. The results of the measurements on the separate samples are given in the table above. For each sample, α_{20} is divided by the per cent conductivity and the quotient given under *C*. *C*, the constant resulting, is the computed value of the temperature coefficient of copper of 100 per cent conductivity.

3. THE SOURCES OF MATERIAL REPRESENTED

Each one of the groups into which the results are divided represents one source of material. These sources, without reference to the order in the table, were the following:

Smelters	Calumet and Hecla Smelting Works, Hubbell, Mich. Quincy Mining Company, Hancock, Mich. Buffalo Smelting Works, Buffalo, N. Y.
Electrolytic refiners	American Smelting and Refining Company, Maurer, N. J. The Baltimore Copper Smelting and Rolling Company, Baltimore, Md. The United States Metals Refining Company, Chrome, N. J. Raritan Copper Works, Perth Amboy, N. J. Nichols Copper Company, Laurel Hill, N. Y. A. Grammont, Pont-de-Cheruy, France.
Wire manufacturers	American Brass Company, Waterbury, Conn. John A. Roebling's Sons Company, Trenton, N. J. Standard Underground Cable Company, Perth Amboy, N. J. Heddernheimer Kupferwerk und Suddeutsche Kabelwerke, Frankfurt-am-Main, Germany. Kabelfabrik-und Drahtindustrie-Actien-Gesellschaft, Vienna, Austria.

It will be seen that a considerable number of the most important producers of copper are included in the list. This country, Germany, France, and Austria are represented. As the samples (except three; see next paragraph) were the usual commercial grade of copper that is sold for electrical purposes, and as the range of conductivity of the samples covers thoroughly the range of such copper, it is believed that the results

TABLE I

TEMPERATURE COEFFICIENTS (1) OBSERVED, AND (2) COMPUTED FOR COPPER OF 100 PER CENT CONDUCTIVITY

Per cent conductivity[2]	α_{20} $\left(=\frac{R_t-R_{20}}{R_{20}[t-20]}\right)$	C $\left(=\frac{\alpha_{20}}{\text{Per cent conductivity}}\right)$	Mean values of *C*	Deviations from final mean
[3]97.44	0.00384_0	0.00394_1		
[3]97.46	384_3	394_3		
[3]97.54	384_6	394_3		
100.22	395_0	394_1	0.00394_2	$+0_4$
100.24	395_2	394_3		
100.29	395_4	394_3		
100.44	395_9	394_2		
[3]97.47	382_5	392_4		
100.11	393_1	392_7	0.00392_6	-1_2
99.96	392_7	392_9		
100.09	392_9	392_6	0.00392_7	-1_1
[3]98.18	386_0	393_2		
[3]98.25	386_0	392_9	0.00393_0	-0_8
99.73	393_5	394_6		
100.16	393_6	393_0	0.00393_8	0
[3]96.56	380_6	394_2		
[3]96.96	382_8	394_5		
99.63	391_7	393_2	0.00393_7	-0_1
99.97	392_7	392_8		
[3]94.13	371_6	394_8		
[3]95.80	378_2	394_8		
96.60	381_5	394_9	0.00394_9	$+1_1$
99.89	394_6	395_0		
[3]97.07	384_0	395_5		
99.75	394_0	395_0	0.00395_2	$+1_4$
[3]97.96	385_3	393_3	0.00393_2	-0_6
100.70	395_9	393_2		
99.14	392_6	396_0	0.00395_6	$+1_8$
99.39	392_5	395_2		
[3]96.95	383_0	395_0	0.00394_3	$+0_5$
100.26	394_6	393_6		
[3]97.84	385_0	393_5	0.00393_2	-0_6
100.54	395_1	393_0		
[3]97.25	382_8	393_6	0.00393_4	-0_4
100.14	393_8	393_3		
[3]97.75	384_5	393_3	0.00393_1	-0_7
100.70	395_7	392_9		

		Mean deviation.
Final mean......................	0.00393_8	$=0_8$
Final mean rounded off.........	0.00394	=0.2%

2 100 per cent conductivity corresponds to resistivity of 0.153022 ohm per meter-gram (or 1.72128 micro-ohms per centimeter cube, density = 8.89), at 20 deg. cent.

3 Hard-drawn wires; the others are annealed.

are representative. The third column of the table shows the agreement of the samples from each source. The fourth column shows the agreement of the various sources. The fifth column gives the deviations of the group means from the final mean. The mean deviation is 0.000008 or 0.2 per cent. The experimental error of the separate measurements is probably not greater than 0.000004, or 0.1 per cent. However, in view of all the circumstances, the mean deviation is remarkably small, and we are justified in saying that the accuracy of the final mean is probably well within 0.00001.

4. EFFECT OF CHEMICAL DIFFERENCES OF SAMPLES

The agreement of C for samples differing in chemical composition is shown throughout the list, and in particular by the seventh group. The samples in this group were of copper refined by smelting. The first three samples of this group are the only ones given in the list which do not represent the usual copper which is sold and accepted for use as electrical conductors. Ths first is a hard-drawn wire and the third an annealed wire of " cupola " copper, known to be highly arsenical. The second is a hard-drawn wire of " silver-bearing " copper, containing 0.17 per cent silver. The fourth in the group is the regular refined copper of the smelter.

5. EFFECT OF PHYSICAL DIFFERENCES OF SAMPLES

The agreement of C for samples differing in physical condition is shown by the first, second, sixth, eighth, ninth, eleventh, twelfth, thirteenth, and fourteenth groups. The wires indicated by a superior figure ([3]) were hard-drawn; the others were annealed. *The effect of hard-drawing and annealing was further tested.* A piece of the same soft wire from which was taken the fifth sample in the table was partially hardened by drawing through dies, and the measurements showed

conductivity = 98.96 per cent, α_{20} = 0.003902, C = 0.003943.

Also, a piece of the hard-drawn wire given second in the table was annealed by heating electrically to a dull-red heat and gave the following

conductivity = 100.15 per cent, α_{20} = 0.003948, C = 0.003942.

Again, the identical sample given first in the table was annealed, and gave

conductivity = 100.14 per cent, α_{20} = 0.003946, C = 0.003941.

The agreement of C before and after the alteration of physical condition in all cases is within the experimental error.

6. EFFECT OF LOCAL HARDENING

The effect of local hardening of a wire was also investigated. This is of importance because in ordinary use copper wire is bent and coiled. Bending is known to produce local hardening and increase of resistance. The increase of resistance is usually considered to be due simply to increase of specific resistance, just as the hardening of a wire by drawing increases the specific resistance. It would therefore be expected that the temperature coefficient would increase as does the resistance. That this view is in error was shown by the following experiments. An annealed wire was bent back and forth at a number of points, and the resistance and temperature coefficient remeasured. The apparent conductivity decreased, while the temperature coefficient scarcely changed at all. The wire was then annealed and remeasured. The results are given in the following table:

	Per cent conductivity	α_{20}	C
Before bending	100.11	0.003931	0.003927
After bending	99.31	0.003926	....
After annealing	99.48	0.003929	....

Another annealed wire was treated more severely, bent, pulled, twisted. The results are given in the following table:

	Per cent conductivity	α_{20}	C
Before distortion	100.44	0.003959	0.003942
After distortion	98.35	0.003931	....
After annealing	98.90	0.003953	....

In this case the apparent conductivity showed a large decrease upon distortion, and the temperature coefficient a slight decrease. We therefore conclude that most of the apparent decrease in conductivity is due to some such cause as change of cross section. This conclusion is strengthened by the result of the annealing. If the decrease in conductivity were due

simply to a hardening, we should expect that the annealing would restore the former conductivity. But we see that the annealing actually raises the apparent conductivity only slightly and raises the temperature coefficient a proportionate amount, in fact restoring practically the original temperature coefficient. The greater part of the decrease in apparent conductivity, due to local distortions, is therefore, caused by local changes in cross section. Ordinary bending, as seen from the first of these two wires, changes the temperature coefficient practically not at all. It will be noticed that the value of C is not computed for the distorted wires in the two preceding tabulations. This is to emphasize the fact that a correct value of C is not obtained with samples which have been bent and distorted; as may be seen, in these cases the value of C would be too high. In the measurement of conductivity the assumption of a uniform sample must be carefully guarded, while this is not necessary in the measurement of temperature coefficient. This will be discussed below.

7. COPPER SAMPLES THAT HAD NEVER BEEN MELTED

Besides the results already given, measurements were made upon some samples of electrolytic copper wire drawn directly from cathode plates without intermediate melting. These were of especially high conductivity because of high purity, the chief gain in conductivity probably being due to freedom from the cuprous oxide introduced in melting.

The results for C lie slightly below any of the values in the table above. They were omitted from the table because this cathode copper was specially prepared for experimental purposes, and the table is intended to represent simply the copper commercially obtainable.

Cathode copper is known to occlude considerable quantities of hydrogen.[5] We might, therefore, expect abnormalities in its properties. The precise explanation of the original low values for C is not, however, apparent; if there were defects in these wires in the nature of local discontinuities we should expect the apparent conductivity to be less than the real conductivity, and the temperature coefficient to be unaffected; hence the value of C would be too high.

Another anomalous case found was that of some native lake

5. Soret-Compts Rendus 107, p. 733; 1888, and 108, p. 1298; 1889. Foerster-ZS Electrochem. 5, p. 508; 1899.

copper which had never been melted down. The wires had been drawn directly from the mass of native copper. Annealed, it had higher conductivity and temperature coefficient than any other copper as yet measured at the Bureau of Standards. The results follow; the first is a hardy drawn wire, the second annealed.

Per cent conductivity	α_{20}	c
99.17	0.003885	0.003918
101.71	0.003978	0.003911

It is to be noted that both these wires and the cathode samples of the preceding paragraph were prepared from copper that had not been melted.

III. Conclusions

1. PROPORTIONALITY OF TEMPERATURE COEFFICIENT AND CONDUCTIVITY

The principal result of this investigation may be expressed in the form of the following practical rule: *The 20 deg. cent. temperature coefficient of a sample of copper is given by multiplying the number expressing the per cent conductivity by* 0.00394. (100 per cent conductivity is taken as corresponding to a resistivity of 0.153022 ohm per meter-gram at 20 deg. cent.) This is intended to apply merely to the copper furnished for electrical uses, and to the temperature range of 10 deg. cent to 100 deg. cent., over which the temperature coefficient was found to be linear. The practical importance of this relation is evident, for it gives the temperature coefficient of any sample when the conductivity is known. Thus, the temperature coefficient for the range of conductivity of commercial copper may be exhibited by the following table:

TEMPERATURE COEFFICIENTS OF COMMERCIAL COPPER

$$R_t = R_{t_1}(1 + \alpha_{t_1}[t - t_1])$$

Ohms per meter-gram at 20 deg. cent.	Per cent conductivity	α_0	α_{15}	α_{20}	α_{25}
0.15940	96	0.00409	0.00386	0.00378	0.00371
0.15776	97	0.00414	0.00390	0.00382	0.00375
0.15614	98	0.00418	0.00394	0.00386	0.00379
0.15457	99	0.00423	0.00398	0.00390	0.00383
0.153022	100	0.00428	0.00402	**0.00394**	0.00386
0.15151	101	0.00432	0.00406	0.00398	0.00390

The above table was calculated by means of the following formula, which holds for any temperature, t_1, and any per cent conductivity, n (expressed decimally—*e.g.*, if per cent conductivity = 99 per cent, n = 0.99):

$$\alpha_{t_1} = \frac{1}{\frac{1}{n\,(.00394)} + (t_1 - 20)}$$

2. THE RESISTIVITY-TEMPERATURE CONSTANT

Conductivity tests are made in connection with the purchase of wire by many refiners, wire manufacturers, makers of instruments, and others. A knowledge of the temperature coefficient is important in the determination of conductivity when the measurements are made at a temperature other than the standard temperature. Our rule can be put in a remarkably convenient form for such cases, *viz.*, *The change of the resistivity per degree cent. of a sample of copper is* 0.000598 *ohm per meter-gram, or* 0.00681 *micro-ohm per centimeter cube.* Accordingly the resistivity as found at any temperature may be reduced to standard temperature simply by adding one of these constants multiplied by the temperature difference. These constants are independent both of the temperature of reference and of observation, and also independent of the sample of copper.

3. TEMPERATURE CORRECTION FOR MEASUREMENTS AGAINST A COPPER STANDARD.

When a determination of conductivity involves a resistance measurement against a copper standard at the same temperature as the test sample, usually no temperature correction is necessary. When, however, an accuracy of 0.01 per cent is striven for, it is often necessary to make a correction. In such cases the meter-gram resistivity at the standard temperature, T, is obtained by adding to the meter-gram resistivity as calculated from the resistance comparison at t deg., the quantity $[(t - T)\ (\delta - \delta_n)\ (0.0039)]$; in which δ = meter-gram resistivity of the sample and δ_n = quotient of 0.000598 by the temperature coefficient of the copper standard. Similarly the centimeter cube resistivity at the standard temperature is obtained by adding to the centimeter cube resistivity as calculated from the resistance comparison at t deg., the quantity $[(t - T)\ (\rho - \rho_n)\ (0.0039)]$; in which ρ = centimeter cube resistivity of the sample and ρ_n = quotient of 0.00681 by the temperature coefficient of the copper standard.

4. EFFECTS OF HARDENING, IMPURITIES, AND DISTORTION ON THE TEMPERATURE COEFFICIENT

A conclusion which follows from the results is that the resistance added to that of pure copper by hardening or by the presence of the small quantities of impurities usually found in refined copper has no temperature coefficient.

As shown above, the ordinary coiling, winding, and bending of a wire may increase its resistance. In such cases there are local changes of dimensions which are much more effective in changing the resistance than the slight hardening caused, and thus such distortions do not materially affect the percentage temperature coefficient. It may therefore be assumed without serious error that the temperature coefficient of a copper wire is the same after winding on a machine or instrument as it was before. Accordingly, if a measurement has been made of either the conductivity or the temperature coefficient of the wire before winding, the temperature coefficient may safely be assumed to be known after winding and may be used in the calculation of temperature rise.

5. THE TEMPERATURE COEFFICIENT AS A MEASUREMENT OF CONDUCTIVITY

The relation between conductivity and temperature coefficient emphasizes the desirability of making a conductivity test on samples used instead of assuming values. It also indicates, however, that the conductivity test can be replaced by a measurement of the temperature coefficient. It is often easier to measure the resistance between two fixed points on a sample at two known temperatures and thus obtain the temperature coefficient than to measure the specific resistance, which is in a sense an absolute measurement. A value can thus be obtained for the conductivity which is reliable, according to the present results, within one-half per cent. Four particular cases suggest themselves in which the measurement of temperature coefficient has considerable advantage over a conductivity measurement.

(*a*) *Odd Shapes.* Unless a uniform sample can be prepared, the determination of conductivity directly is hopeless. Through the temperature coefficient, the conductivity may be known for a specimen of any shape, without the danger of altering its properties by the preparation of a uniform sample.

(*b*) *Short Samples.* For very short samples, the difficulty of measurement of the dimensions and the possible uncertainty

of the current distribution limit the use of conductivity measurement. Neither objection applies to the determination of the temperature coefficient.

(*c*) *Wires that have been Distorted or Bent.* As shown above, the apparent conductivity of a wire that has once been distorted by bending is incorrect, while such treatment does not materially affect the temperature coefficient or the real conductivity. The temperature coefficient, therefore, gives the real conductivity better in such cases than does a direct measurement of the conductivity.

(*d*) *The Estimation of Chemical Purity.* The use of conductivity as a criterion of chemical purity is familiar. Evidently the temperature coefficient is fully as reliable a criterion as the conductivity, and is more generally applicable, and is often an easier test to apply than either the conductivity or chemical determinations. Indeed, the temperature coefficient is used as a criterion of purity in the selection of platinum for platinum thermometers. It is also interesting to know that the temperature coefficient is used commercially as a criterion of purity for some of the metals used in incandescent lamp manufacture; it is the most delicate test available of some of the desirable properties of the pure material, surpassing even the chemical tests, which are much more laborious.

6. EXPLANATION OF DISAGREEMENTS OF PREVIOUS OBSERVERS

We now have an explanation of the disagreements of the results of previous observers, aside from the errors of their measurements. For example, one of the most carefully established previous values, that adopted by the American Institute of Electrical Engineers, was the result of over 100 determinations made by Messrs. Robinson and Holz, of the General Electric Company. They found variations in the value and considered 0.0042 as the best that could be done in assigning a mean. As may be seen, the same conclusion could be reached from the data of this paper if the temperature coefficient only were considered. 0.0042 is the temperature coefficient, α_0, for copper of conductivity equal to 98.3 per cent. If it is used for a sample whose conductivity is 100 per cent, the error of the computed value at 100 deg. cent. is over one-half per cent. (If the French coefficient is used in a similar case, the error is 2 per cent.) It is interesting to notice that the A.I.E.E. temperature coefficient happens to correspond very closely to 98 per cent conductivity, which has been the

conductivity usually specified for annealed copper on purchases in this country.

7. VALUES SUGGESTED FOR ANNEALED AND HARD-DRAWN COPPER

According to the results of an investigation now being carried out at the Bureau of Standards, a fair value to assume for the conductivity of good commercial *annealed* copper wire (in cases where assumption is unavoidable) is 100 per cent, for which

$$\alpha_0 = 0.00428,\ \alpha_{15} = 0.00402,\ \alpha_{20} = 0.00394, \text{ and } \alpha_{25} = 0.00386.$$

This value would usually apply to instruments and machines, since they are generally wound with annealed wire. Similarly, the conductivity of good commercial ***hard-drawn*** copper wire may be taken as 97.3 per cent, for which

$$\alpha_0 = 0.00415,\ \alpha_{15} = 0.00391,\ \alpha_{20} = 0.00383, \text{ and } \alpha_{25} = 0.00376.$$

IV. THE MATHEMATICAL EXPRESSION OF THE TEMPERATURE COEFFICIENT

The simple mathematical relations between the different methods of expressing the temperature coefficient are sometimes confused; it is therefore thought desirable to include a discussion of them in this paper. . . . See the original paper.

V. SUMMARY

1. The foregoing investigation shows that, for representative samples of the copper at present furnished for electrical use, the *conductivity and temperature coefficient are proportional*, to a high degree of accuracy for differences in physical condition, and to a fair accuracy for differences in chemical composition of samples.

2. This relation may be put in the following very convenient form for reducing the results of resistivity measurements to a standard temperature: *The change of the resistivity per degree cent. of a sample of copper is* 0.000598 *ohm per meter-gram, or* 0.00681 *micro-ohm per centimeter cube.*

3. The distortions caused by bending and winding a wire are shown to produce no material change in the temperature coefficient; so that the temperature rise in machines and instruments may be calculated from measurements of the resistance of the windings with greater confidence than heretofore.

4. The measurement of temperature coefficient is shown to present an advantageous substitute for the direct measurement of conductivity in a number of cases.

5. A discussion is given of the mathematical relations between the different methods of expressing the temperature coefficient.